G.E.C. Journal

VOL. XX. JULY, 1953 No. 3

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Published by

THE GENERAL ELECTRIC COMPANY LIMITED
Magnet House, Kingsway, London, England.

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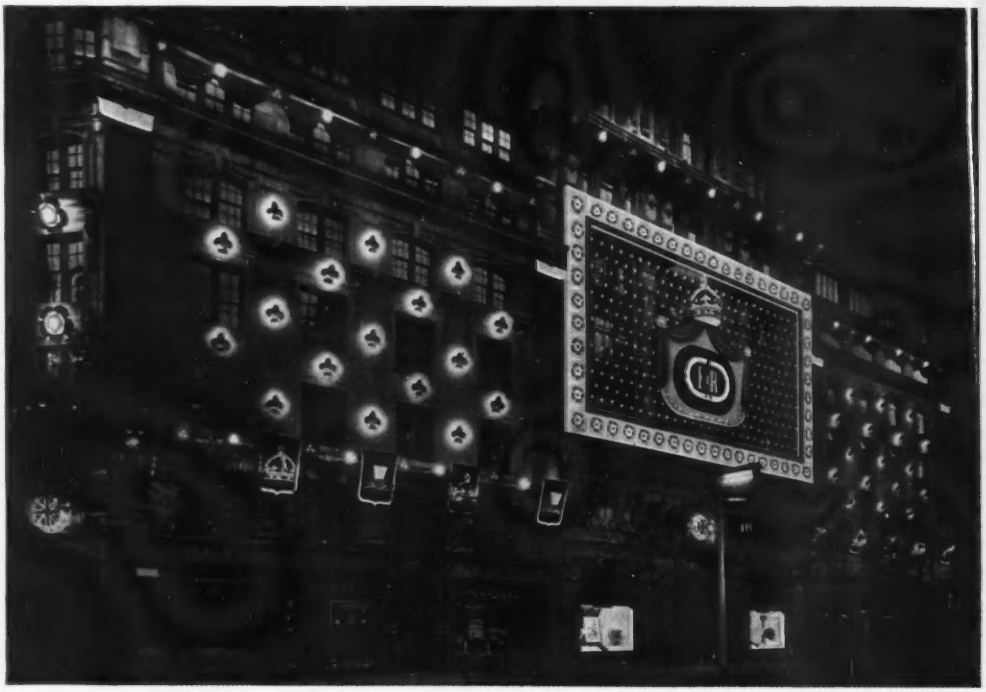


The decorated façade of Magnet House, Kingsway, illuminated during the Coronation celebrations.

Regent Street, as seen from Piccadilly Circus, illuminated for the Coronation of Her Majesty Queen Elizabeth II.

Coronation Lighting

In connection with the celebrations following the Coronation of Her Majesty Queen Elizabeth II, the G.E.C. was responsible for the floodlighting and decorative illumination of many notable streets and buildings at home and overseas.

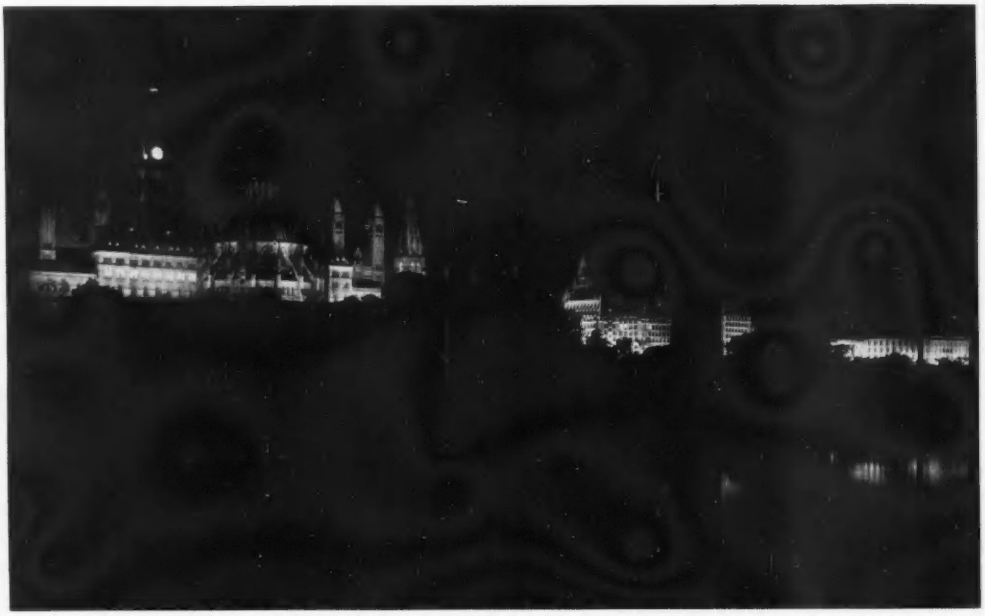
Magnet House, a colour photograph of which is reproduced on the opposite page, was an outstanding feature of the illuminations in Kingsway, while Regent Street, also shown in colour, was typical of the many schemes executed in the Capital.

Other important buildings for which decorative lighting equipment was supplied included the Bank of England, the Port of London Authority, Imperial Chemical Industries, the Automobile Association, Cable and Wireless, Pearl Assurance and Hurlingham Club.

Overseas, decorative illumination equipment was supplied to such widely separated places as Canada and New Zealand, South Africa and Malaya, Malta and Ceylon, Gibraltar, Hong Kong, Cyprus, Mauritius and the West Indies.

Overleaf are shown views of the Parliament Buildings, Ottawa, and of the well-known Fullerton Building, Singapore.

Floodlighting of the Bank of England.



The rear of Parliament Buildings, Ottawa, with the Library, seen from the Inter-provincial Bridge.

The Fullerton Building, Singapore, which houses the General Post Office, Singapore Club and many Government Offices.

Battery Locomotives for London Transport Executive

By E. H. CROFT, A.M.I.C.E., M.I.E.E.
Traction Department, Witton.

INTRODUCTION.

DURING the first half of 1952 the last of seven battery locomotives were delivered to the London Transport Executive and six are now in service. The G.E.C. were main contractors for the electrical equipments which are similar to six supplied before the war and are of somewhat unusual design.

On all electric railways some form of self-propelled vehicle, independent of line supply, may be considered essential for maintenance and extension work, as it enables ballast or works trains to operate when power is switched off. This has many obvious advantages both on regular maintenance and new works. These vehicles may also be usefully employed on other duties such as cable laying and sundry shunting duties and in some cases may make it unnecessary to electrify certain sidings.

On an electric railway system such as that of the London Transport Executive which includes such a large percentage of cut and cover lines or actual tubes, a battery as the source of energy has many advantages. Except during charging it produces no objectionable fumes and may be charged from the supply system at any part of the line outside the actual tubes. In addition, the battery locomotive can be run as an electric locomotive from the track whenever the section is alive, and can also serve as a source of energy for running electrically driven maintenance equipment such as drills and concrete mixers.

It is not surprising, therefore, that the London Underground system has employed battery rail vehicles of one kind or another for a great many years.

Fig. 1.—A typical battery locomotive of the double, two-axle, non-articulated bogie type.

As far as is known, the first battery locomotives were put into operation in 1905 on the Great Northern, Piccadilly and Brompton Railway. They were arranged for battery operation only and the charging equipment was situated at suitable depots. Of these two locomotives, one was transferred to the Charing Cross, Euston & Hampstead Railway in 1906, this line being opened in 1907. Both were scrapped in 1918.

In 1906 the Metropolitan District Railway obtained two battery locomotives for surface line service. These, again, were primarily for battery operation and were charged by equipment at Ealing Common Depot. They were not entirely satisfactory and by 1912 the batteries had been removed and the locomotives turned over for conductor rail operation. These converted locomotives are still in use between the Ealing Common Depot and the Acton Works.

About 1910 an old Central London car was converted to battery operation and later, in 1924, another was similarly changed over. By a simple arrangement they were able to run off the battery or on either Underground system, i.e. from single or double conductor rails. In 1931-2 three further conversions were made.

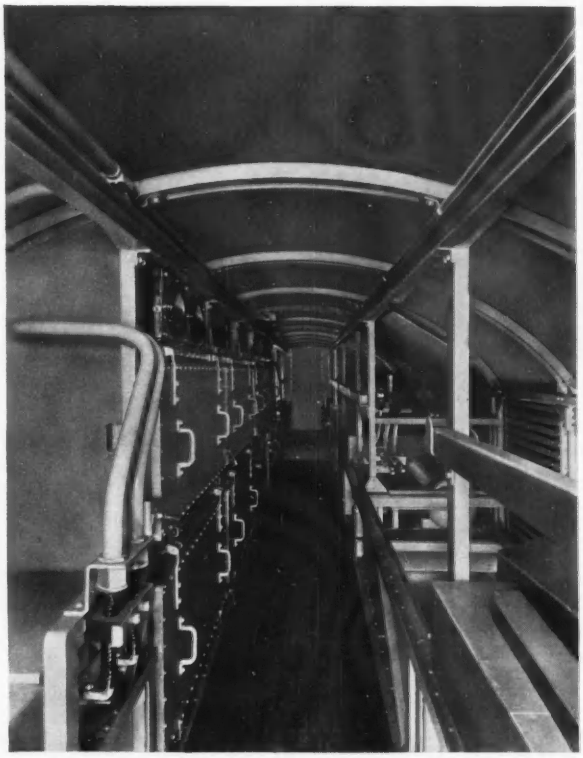


Fig. 2.—Interior of the locomotive, showing the electrical equipment cubicle on the left and the battery tanks on the right.

From what has been said, it will be realised that the battery locomotive has fully established its usefulness and the Underground engineers have had considerable experience upon which they can judge its applications, specify the performance and general characteristics required, and assist the manufacturer in design.

In 1937 orders were placed for electrical equipments, the G.E.C. receiving a contract for six equipments with series, series-parallel, parallel and resistance control.

The performance specified was naturally rather severe, some of the essential requirements being as given below.

Two locomotives, operating in multiple unit, were required to propel a 200 ton trailing load to site four and three-quarter miles from the depot. Three miles of the journey was on normal electrified track, and speeds had to be such as to avoid interference with normal traffic, the remaining distance being rough unelectrified track.

On site, the locomotive had to inch the train forward on gradients up to 1 in 30 and be capable of returning to depot with a light train, the total time period being about nine hours.

Gradients of up to 1 in 61 for one and a half miles had to be met.

For cable laying a single locomotive had to haul steadily a trailing load of 100 tons at speeds below 3 m.p.h.

Consideration of the above is sufficient to indicate the severity of the service both from the point of view of the capacity of the battery and the wide range of running speeds.

For the locomotives supplied before and after the war respectively the London Transport Executive placed contracts for the mechanical parts with the Gloucester Railway Carriage and Wagon Co., Ltd., and R. Y. Pickering & Co. Ltd., Wishaw, Scotland. Fig. 1 shows one of the completed locomotives. It is of the double, two-axle non-articulated bogie type. Each axle is motored; a driving cab is provided at each end, and the body carries the control and auxiliary equipment which is housed in a special compart-

ment, the batteries being carried in special tanks or trays.

The general mechanical construction, while embodying well-proven and simple constructional details, is in some ways novel. The main frame is of the normal riveted construction but has some unusual features due to the massive headstocks needed to accommodate various types of stock, to the dropped cab floor required so as to allow head room within the Tube loading gauge, and to the heavy battery load carried. The bogies, also of riveted construction, are of the swing link, spring bolster type, the load being taken on the king pin seatings ; transverse limit stops are provided.

The body work is relatively light and includes both welded and riveted construction. The cubicle for the electrical control and auxiliary equipment is situated on one side of the central gangway at the centre of the locomotive. Access can be obtained by removing covers alongside the gangway and on the side of the locomotive. Most of the remaining space on each side of the gangway is taken up by the batteries which are contained in bitumen lined tanks with suitable drainage, and are well ventilated by the louvred sides that are easily removable. The tops of the batteries are covered in by suitable wooden box-type screens.

The previous locomotives had removable roofs to permit withdrawal of batteries, but these later locomotives have two rails along the gangway near the roof. A portable jib crane can be assembled on these rails allowing any cell to be swung out of its tank and then lowered down through a trap-door in the floor to a pit. It is felt that this will afford easier maintenance or replacement of batteries besides the advantages of a fixed roof. It is interesting to note that the buffers may be swung out of the way for tube stock operation. In fig. 1 the top hinge and wood support block may be seen.

Fig. 2 shows the inside of the locomotive, the electrical equipment cubicle with the dust tight covers may be seen on the left, while a battery tank with cover removed is visible on the right. Towards the end of the gangway, on the right, the wooden covers for the batteries are seen in place. It will be noted that there is a battery section at each end of the apparatus cubicle on the left-hand side. On each side of the gangway, almost against the roof, are the two channel rails for the portable jib crane. Fig. 3 shows the main, auxiliary and control equipment in the cubicle with the covers removed. The electro-pneumatic contactors are mounted in two groups while a centre panel carries the various relays, fuses and resistances. Underneath are the reversers and the main isolator.

The battery, main and charging fuses, together with certain control air details are mounted in a space opposite the equipment cubicle and between two main groups of cells. They may be seen in fig. 2 which also shows the

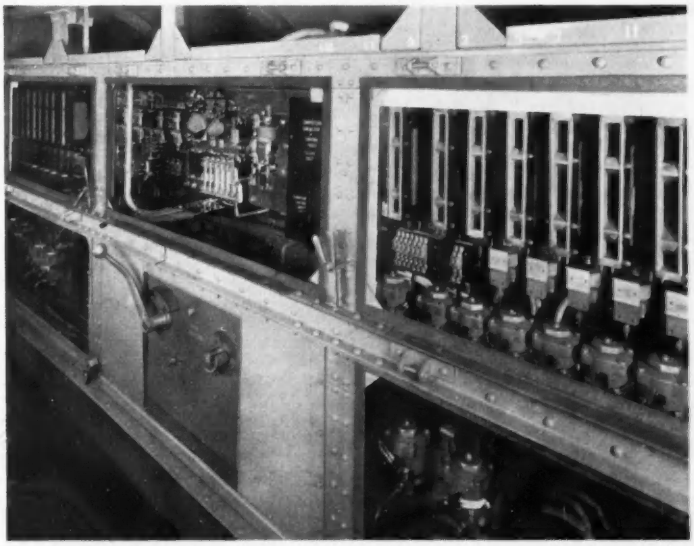


Fig. 3.—The electrical equipment cubicle with covers removed, showing the main, auxiliary and control equipment.

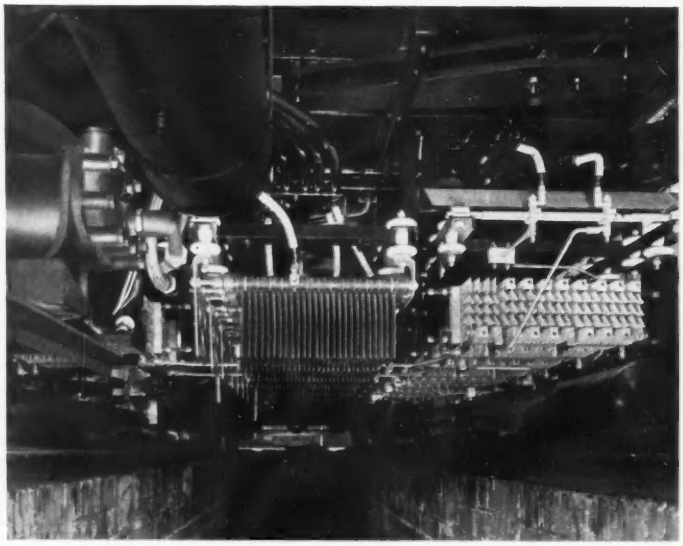


Fig. 4.—The under-frame of the locomotive, showing the main starting, battery charging and compressor resistances.

screens above the fuses. The remaining equipment is carried on the under frame and includes the main starting, battery charging and compressor resistances, the compressor and motor, shed receptacles, main power fuses and various brake equipment (fig. 4).

Table 1 gives general data regarding the locomotives.

MAIN POWER CIRCUITS.

Fig. 5 shows the arrangement of the power circuits. It will be noted that three motor combinations are adopted namely : series, series-parallel, and parallel. Both transitions are of the shunt type, this being the simplest for locomotives associated with variable loads. As is well known, the bridge transition is less suitable for such conditions unless considerable complications are added. Only two combinations of starting resistance are used. In spite of the very onerous conditions placed on the resistances by the locomotive requirements, this simplification to two combinations more than meets all requirements by introducing a series-parallel arrangement within each group by means of the contactors 8 and 9, the stagger-notching of the two sections when in parallel and the arrangement of the control to permit the best notching sequence in each motor combination. This will be more clearly followed by an examination of the sequence chart on fig. 5. As the London underground transport system is provided with a positive and negative conductor rail, the circuits are arranged to be opened by contactors on both the negative and positive supply and the overload system is similarly arranged.

CONTROL SYSTEM.

Fig. 6 shows the control circuits. The operating coils of the air valves are marked to correspond with the marking of the contactors in fig. 5. Selection of running on track or battery is by means of the control key switch which is operated by a control key, one only of which is in the possession of the driver. It can be inserted only when the switch is in the "off" position and cannot be moved from "track" to "battery" unless the switch is unlocked by means of the reverser key of the master controller. When so unlocked, the reverser key is retained and can be withdrawn only when the switch is locked again. It follows that the switch is always free to be opened in any emergency, but cannot be moved from "track" to

TABLE 1.

Weight of complete locomotive	59·8 tons
Weight of battery and wedges	16·2 tons
Weight of four driving motors, gears and cases	11·0 tons
Weight of main, auxiliary and control equipment, excluding mechanical parts or airbrake details	3·25 tons
Weight of mechanical parts, including mechanical and airbrake details, compressor and motor	29·35 tons
Length over headstock	52 ft. 10 in.
Bogie centres	31 ft. 0 in.
Bogie wheel base	7 ft. 3 in.
Gauge	4 ft. 8½ in.
Overall height	9 ft. 5¼ in.
Overall width	8 ft. 2¾ in.
Wheel diameter	3 ft.
Continuous rating of each motor	150 h.p.
Hourly rating of each motor	210 h.p.
Total tractive effort at continuous rating	11,600 lb.
Tractive effort at 25 per cent adhesion	33,500 lb.

" battery " or " battery " to " track " unless the main motor circuits are dead. Thus all possibility of the changeover switch operating with power on is eliminated.

The master controller embodies a main drum and a reverse drum provided with the usual mechanical interlocking to prevent the reverser being thrown if power has not been switched off by the main handle, and when the reverse key is withdrawn the whole controller is locked off and is inoperative. It should be specially noticed that all three combinations are on one handle and no separate combination handle is provided as is the more usual practice. The reasons for this are partly due to the desire to make the driving as similar as possible to that of a motor coach, but mainly due to the fact that it permits the best value of starting resistance being selected for each step on each combination instead of having to compromise between the combinations. A control governor, operative only in the forward direction, is included. The large number of train lines for multiple operation requires the provision of two sets of receptacles. The interlocks of the valve circuits call for no special comment beyond stating that the minimum number of interlocks is used to ensure safety and correct operation of transitions and sequence. To meet emergency conditions either pair of motors may be cut out by means of a master cut-out switch. Double overload relays are provided on each pole, the negative

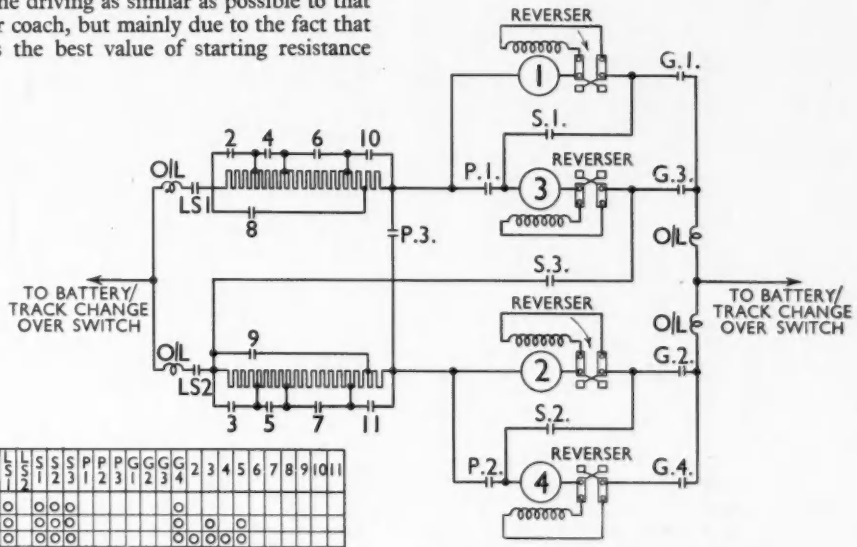
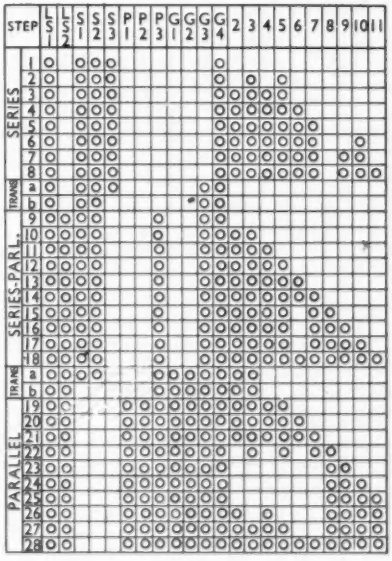


Fig. 5.—Arrangement of power circuits.



being associated with *G*1, *G*3, *G*2 and *G*4 contactors, and the ' positive ' associated with *LS*1 and *LS*2 contactors.

Each relay is of the type that is set by means of a setting coil energised by pressing the set button, with the controller in the off position, and then self-latching. On an overcurrent in either current coil the latch is tripped and the relay operates and opens the associated contactors. If it is desired to cut out one locomotive entirely when more than one are operating together this may easily be done by the control cut-out switch.

AUXILIARY SCHEME.

Fig. 7 shows the auxiliary circuits in schematic form. The power supply for all circuits is

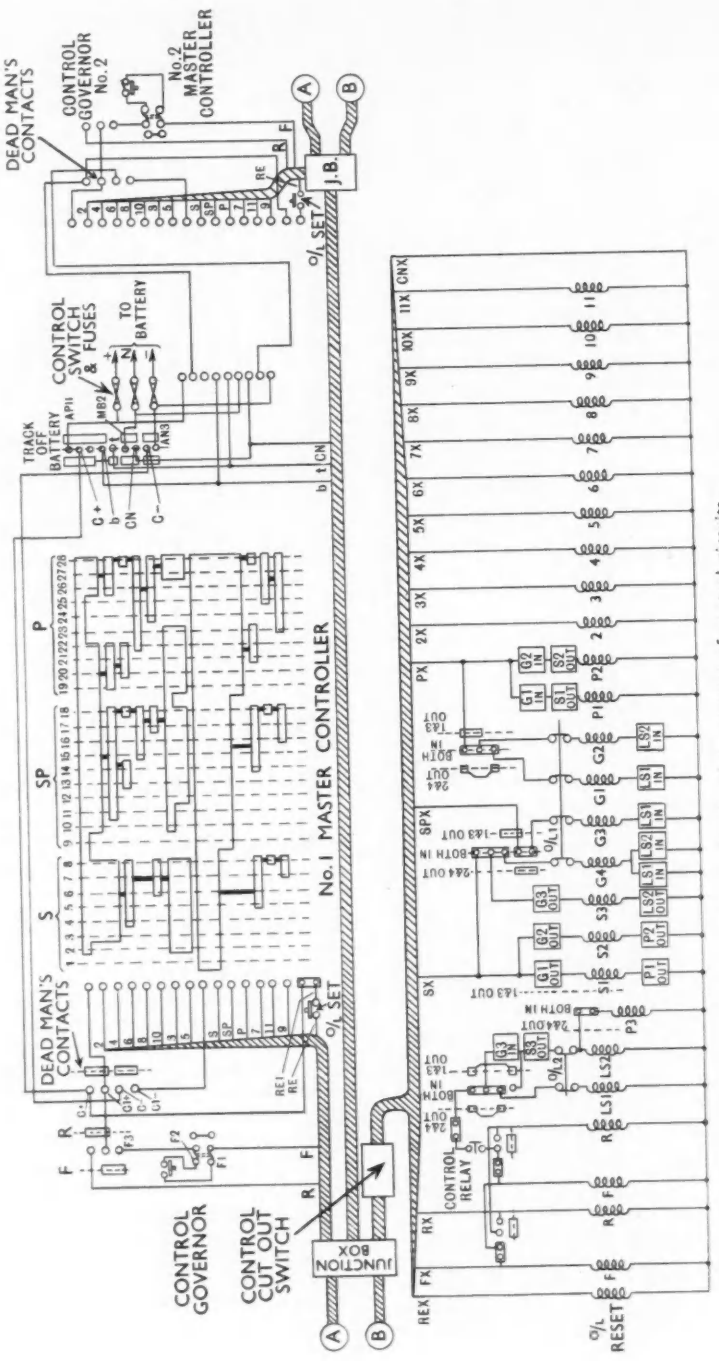


Fig. 6.—Arrangement of control circuits.

collected by either pair of the four positive shoes and both negative shoes. Two shed receptacles permit power to be taken from a shed supply when required.

In addition to the overload system of the power circuits, and various other fuses, a positive and negative main equipment fuse is arranged in each feed as close to the shoes as possible. The main isolator is an important item of equipment. It is provided with four positions. The first gives complete isolation from the track supply for maintenance and inspection; the second allows the batteries to be placed on a gassing charge while the motor circuits are isolated; the third allows the batteries to be under normal semi-automatic charging while the motors are isolated and the fourth makes the circuits of the main motors and cuts off the charging circuits. Originally it was suggested that charging of the battery should take place automatically during running on the "surface" lines; but this scheme was abandoned as it was considered to have no advantages for the L.T.E. and was not permissible in the tubes. To prevent the changeover switch breaking current a simple combined lock and switch is fitted. When this is locked, the associated master contacts 1, 2 and 3 permit the battery circuits, the compressor circuits, and the main power circuits to be formed. When it is unlocked all these contacts are broken and therefore all power circuits are open. When the switch is locked, the isolator cannot be moved from the isolated position to either charge position, or vice versa, and similarly it cannot be moved from "motors in" to the two charge positions, or vice versa. Thus it cannot under any conditions break current. The lock is operated by the reverser key of the master controller, which is retained in the lock when in the unlocked position, but is free to be removed in the locked position. By this means complete safety is ensured and the danger of breaking main current avoided. The "track" to "battery" changeover switch is of the electro-pneumatic remote control type as already described.

Charging of the battery is by means of series resistances. Since the average line voltage is 575 and the battery consists of 160 cells, the charging has not a very high efficiency but is nevertheless very simple and reliable and requires no complicated rotary machines, the housing of which on the locomotive would involve considerable disadvantages due to bulk and weight. Three rates of charging are provided; one for a gassing charge, one for the full charge of a discharged battery, and an intermediate one for normal charging when the battery is partially charged. These rates are obtained by means of three sections of resistance and three all-electric contactors *B*1, *B*2 and *B*3. Closing of contactor *B*1 brings in one section of resistance and gasses the battery, the closing of contactor *B*2 brings in a further section of resistance and the two in parallel pass the intermediate charging current, the full rate is introduced by bringing in a third section by closing of contactor *B*3.

These three contactors are energised from the battery itself, and have a low minimum operating voltage so that they may function correctly on an over-discharged battery. They are primarily fed by placing the main isolator on one of its two charging positions and operating the lock. If placed in the "gas battery" position, contactor *B*1 only is fed, whereas if it is placed on the "charge battery" position all three contactors are fed. Actual energisation of the contactor coils is dependent on certain relays. The first is a simple voltage relay connected across the supply the contacts of which directly control the contactor *B*1 and, indirectly, contactors *B*2 and *B*3 by virtue of the *B*1 interlock in their common feed. Associated with this voltage relay is a reverse current relay *RCR*, having a series coil in the main circuit and a shunt polarising coil energised from the battery. This relay has contacts in the circuit of the voltage relay mentioned above and the two operate together as a cut-in and cut-out battery relay, with contactor *B*1 functioning as the main battery connecting contactor. A further voltage relay, *V*1, is provided which automatically reduces the charging current at a predetermined voltage, corresponding approximately to the point at which the battery is about two-thirds charged. Gassing charges and the eventual termination of normal charging are left to the care of the shed staff.

The lighting circuits which are fed off the battery call for no special comment except as regards the simple method of adjusting the voltage. Each lamp circuit includes a series resistance, a major section of which is short-circuited by contacts on the main isolator when all power circuits are isolated, and is similarly short-circuited when motors are in circuit and running on track. Thus, whenever the battery is on charge, the resistance is in circuit to reduce the lamp voltage. Each cab has a suitable heater fed from the battery, and suitable plugs are arranged for taking off a battery supply to cement mixers and similar track repair equipment. The compressor motor has simple voltage adjustment as described for the lights and is controlled in the usual manner by means of a compressor governor and contactor. It may have

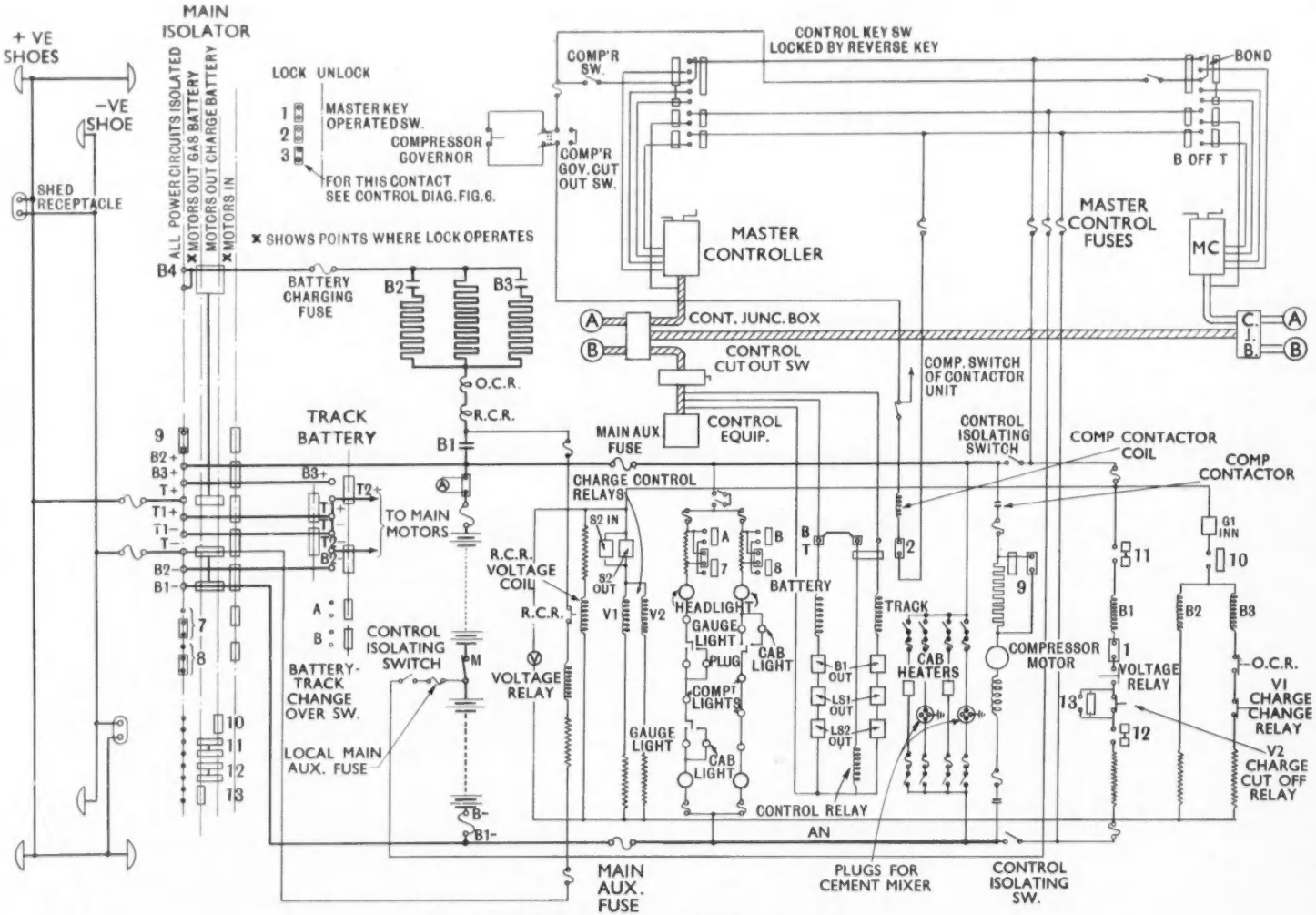


Fig. 7.—Schematic diagram of auxiliary circuits.

been noticed that the control is run on a three-wire system from the battery, thus the control isolating switch is of the triple pole type, and triple pole fuses are provided.

BATTERY.

The batteries are of standard "Kathanode" traction design, type LKC.49 having a capacity of 1,008 ampere hours at the five-hour rate of discharge. Each cell measures 16⅝ in. by 7 in. by 22 in. high over the connectors and weighs approximately 195 lb. The cells are arranged in ten separate compartments with sixteen cells in each and the boxes are ribbed to assist cooling.

The triple separation between positive and negative plates, with the use of glass wool separators, ensures effective support for the positive, active material and results in a compact and resilient assembly which is able to withstand mechanical shock and vibration.

The glass wool separators obviate the necessity for an intricate small mesh grid and the positive grid is therefore of very robust construction comprising ribs of ample section to minimise the effects of electrolytic corrosion and provide maximum mechanical strength, thus ensuring reliability in service and long life. The negative plates are designed to give the optimum capacity consistent with ample mechanical strength and conductivity. The edges of the negative plates are insulated in accordance with British Patent No. 666,753, a method that has proved completely successful in preventing the development of internal short circuits.

In the process of assembling the complete plate group into its container the glass wool sheets are compressed so that the positive active material is always held in good electrical contact with the grid and the necessity for the periodical removal of sediment is completely eliminated.

This method of construction provides a low resistance cell of high efficiency and power/weight ratio, giving a voltage characteristic which is well maintained over the greater part of the discharge.

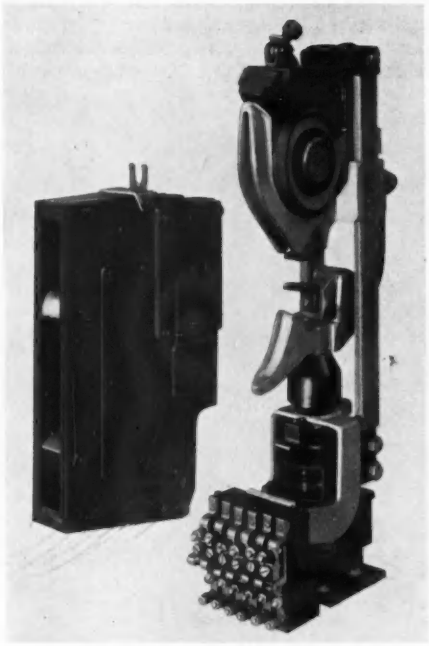


Fig. 8.—The main electro-pneumatic contactor.

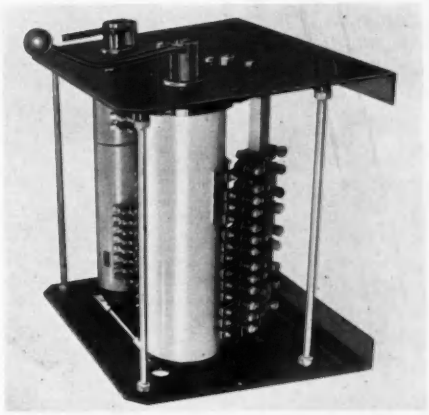


Fig. 9.—The main isolator.

MAIN MOTORS.

The London Transport Executive supplied the main motors from reserve stocks. To meet the required performance characteristic for the new locomotives and to permit multiple operation with the old, the L.T.E. modified them by alterations to the gear ratio, air-gap and field coil windings to data supplied by the G.E.C. These motors were of the Company's design and manufacture, and approximately 1,800 were supplied between 1925 and 1938, after which changes in the L.T.E. designs for new rolling stock resulted in the Company's supplying large quantities of an entirely new type of

Fig. 7.—Schematic diagram of auxiliary circuits.

motor specially suited to the new type coaches for use on the Tube and surface lines.

CONTROL APPARATUS.

The main power electro-pneumatic contactor, shown in fig. 8, is of a fully standardised design,

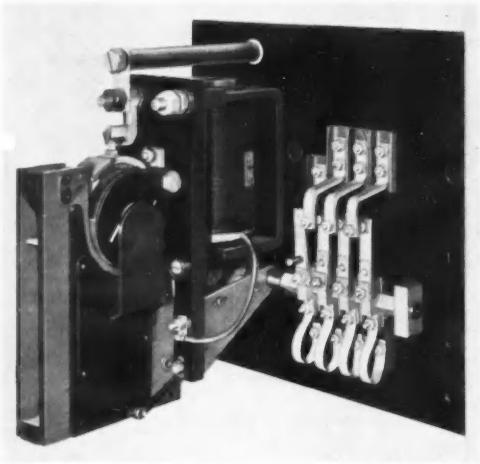


Fig. 10.—Auxiliary contactor for battery charging.

and is used for many equipments. It is built upon two steel side bars, tied at the top by a casting which also forms the top fixing lug, and at the bottom by the air cylinder unit. The bars are insulated by means of bakelite wraps, and the magnetic blow-out system and top contact are clamped to them. The moving contact is carried on an insulator fixed to an extension of the piston rod. By means of a knuckling arm the contact is subjected to the correct tipping and rubbing when closing, and when fully closed has the direct thrust of the piston upon it. The interlocks are carried on the front for accessibility. The arc chute which is readily removable also carries the iron side plates of the blow-out system. The controlling electrically operated air valve is carried on a separate mounting below the interlocks.

As previously mentioned, the main isolator plays an important part in the electrical scheme, and fig. 9 shows the simple and rugged construction of this component. Main and auxiliary fingers are carried on bakelite insulated steel bars, while the contacts are carried on bakelite cylinders mounted on spiders in the usual way. The main drum having fingers on each side is seen with one set of fingers to the front, and is operated directly by the large handle on the right. The lock, operated by the reverse key, carries the contact drum seen on the right behind the main drum, while the interlock drum associated with the main drum is carried freely on the lock shaft and is linked to the main drum by the rod seen on the left. The mechanical interlocking between the two operating handles is situated against the inside of the right-hand end-frame.

Fig. 10 shows the construction of the auxiliary all-electric contactors used for battery charging and other auxiliary purposes. The magnet frame forms the base and is carried from a bakelite panel. The moving contact arm is provided with the usual tipping and rubbing action and the operating arm is of the plunger type. The top contact with the blow-out system is carried on a bakelite base fixed to the front of the magnet frame ; the interlocks are carried at the side. The arc chute is readily removable for inspection.

The control key switch, which, as previously mentioned, also selects " track " or " battery " operation, is of the bakelite cylinder or drum type. Fig. 11 clearly shows the construction, and how the two removable keys are accommodated. The one facing the front is the standard L.T.E. driver's control switch key. The method of preventing insertion or withdrawal except in the " off " position may be clearly followed, projecting pins in the key fouling the shrouding except in the " off " position where additional slots are provided. On the right the reverser key is

Fig. 11.—Control key switch.

clearly visible inserted in the lock. When this key unlocks the switch, the reverser key is retained until the switch is locked again. Obviously the reverser key must not be available to the driver for the master controller until the control switch is locked and prevented from moving from "track" to "battery". The switch may always be operated to "off".

As already noted, the master controller embodies control of all three combinations on the one main drum which accordingly is of a fairly large diameter. Fig. 12 shows the general design. Fingers are of a standard type, mounting is by the use of bakelite covered steel bars. The main drum is of bakelite, while for the dead man's and reverser drums individual castings are used. The dead man's button is seen on the top of the handle grip, being retained in the down position by the palm of the hand when driving. On the left of the top plate is the reverser key, which is provided with the usual interlocks, to prevent its being operated unless the main handle is in the "off" position. Further, it cannot be removed except when the main handle is in the "off" position and it is in mid-position. In this position the main handle is locked in "off". Thus, when once the reverser key is removed, the controller is completely inoperable. On the left of the main drum may be seen the dead man's contacts, provided with blow-outs, and underneath the reverser contacts, the dead man's drum being carried freely on the reverser shaft and operated by a suitable link mechanism.

Fig. 13 shows the charge control relay, which is of the clapper or cantilever type, the hinge taking the form of a knife edge, the contacts being of the silver disc and pin type. All the components are built on to a light pressed steel backplate. Ample adjustment is provided, and the coil is connected in series with a resistance to reduce the effects of a hot or cold coil.

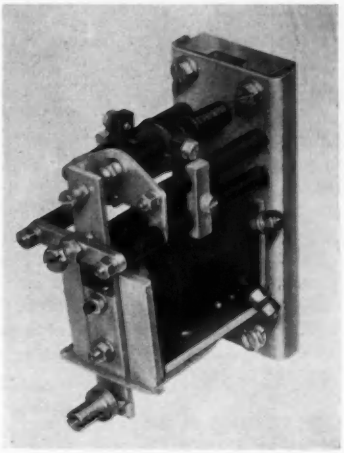


Fig. 13.—The charge control relay.

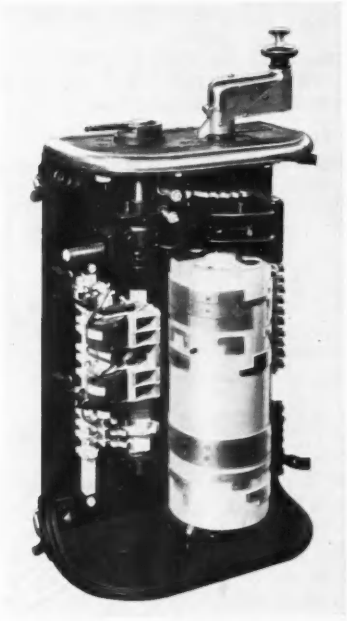


Fig. 12.—The master controller.

In conclusion, it can be claimed that the continuous good service being given by the locomotives supplied before the war, added to the equally good performance of those recently delivered, not only justifies the use of battery locomotives, but also confirms the suitability of the electrical equipment designed and built to meet the special duty demanded of them.

ACKNOWLEDGMENT.

Acknowledgment is made to the London Transport Executive for their assistance in the preparation of this article and for their permission to publish the foregoing information and illustrations.

A Crystal Triode Push-pull Amplifier

By J. I. MISSEN, B.Sc., A.R.C.S.
G.E.C. Research Laboratories

The paper describes a push-pull output stage incorporating crystal triodes. The circuit has been designed specifically to take advantage of the operating conditions peculiar to these devices. Although the maximum collector dissipation of the point contact triode is 100 milliwatts, the circuit is capable of delivering an output power of 400 milliwatts. This is about ten times larger than that obtainable in a conventional crystal triode output circuit.

(1) INTRODUCTION.

THE fact that a fine wire whisker in contact with a semi-conducting material, such as silicon or germanium, exhibits rectifying properties has been known for many years. However, in 1948, Bardeen and Brattain[1] of the Bell Telephone Laboratories in the U.S.A., discovered that if two whiskers were placed close together on an etched surface of a germanium wafer, it was possible to control the current flowing in one whisker by variation of the current in the other.

In operation, a negative potential is applied between one whisker called the collector and a large area contact soldered to the back of the germanium wafer, called the base. The collector and base are then functioning as a diode biased in the direction of low conduction. If a positive potential is applied between the second whisker (emitter) and base, the collector current increases. The emitter functions as a diode which is biased in the direction of easy current flow; it will therefore appear as a low impedance. The collector on the other hand, is biased in the reverse direction and will behave as a high impedance.

If an alternating voltage is applied in series with a positive bias between emitter and base, then an amplified voltage will appear across a resistor connected between collector and base, in series with a negative bias, as shown in fig. 1.

If the resistor R is matched to the collector impedance, a considerable power gain can be obtained. In typical triodes, values of about 22 db are possible.

(2) GERMANIUM TRIODE DESIGN.

The point contact germanium triode, or transistor, possesses a number of advantages over the conventional thermionic valve, notably its small size, rugged construction, instant operation due to the absence of a heater, and a very long life.

Fig. 2(a) shows the construction of the G.E.C. crystal triode. The two leads at one end are connected to the emitter and collector respectively (the collector is colour coded), while the lead at the other end makes contact to the base. An insulated metal can encloses the unit.

In fig. 2(b) the two whiskers are clearly visible making contact with the germanium wafer which is soldered to a central stub.

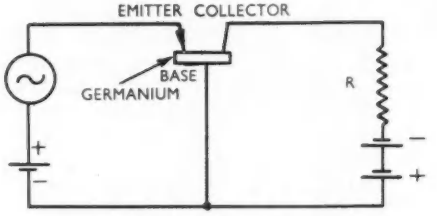


Fig. 1.—Crystal triode amplifier circuit.

(3) ELECTRICAL CHARACTERISTICS.

The crystal triode is essentially a current-operated device, and typical static characteristics are shown in fig. 3. Collector current is plotted against collector voltage for various emitter currents. No appreciable control over collector current is exercised by the emitter for negative voltages or currents. The minimum collector current for a given collector voltage is therefore determined by zero emitter current.

The electrical characteristics of a germanium triode deteriorate with rise of temperature, and

it is therefore important to keep the temperature as low as possible. The heat capacity of the assembly is small, so that the collector dissipation is limited. In the present design, this is rated at 100 mW.

When used as an A.C. amplifier the power developed in a given collector load resistor, is obtained by drawing a load line from a given H.T. voltage as shown in fig. 3. The power output is

$$\frac{(V_1 - V_2)\,(I_2 - I_1)}{(2\sqrt{2})^2} \qquad (1)$$

where $(V_1 - V_2)$ and $(I_2 - I_1)$ are the peak-to-peak collector voltage and current swings respectively.

Fig. 4 shows the anode current/anode voltage characteristics for a typical thermionic triode (type L63). The power output for a particular load will be given by

$$\frac{(V_1' - V_2')\,(I_2' - I_1')}{(2\sqrt{2})^2} \qquad (2)$$

A comparison between the characteristics of the crystal and thermionic triodes brings out important differences. When used as a Class B amplifier, the thermionic triode is biased to cut-off, so that the anode dissipation in the quiescent condition is zero. In the crystal triode, this is not possible, as the lowest collector current under any emitter bias condition, is still finite. In fig. 3, this corresponds to point *A*, and for the operating conditions assumed, the dissipation is 88 mW, which is approaching the maximum dissipation rating. The load line has been drawn tangential to the 100 mW dissipation curve, and the maximum power output is 20 mW.

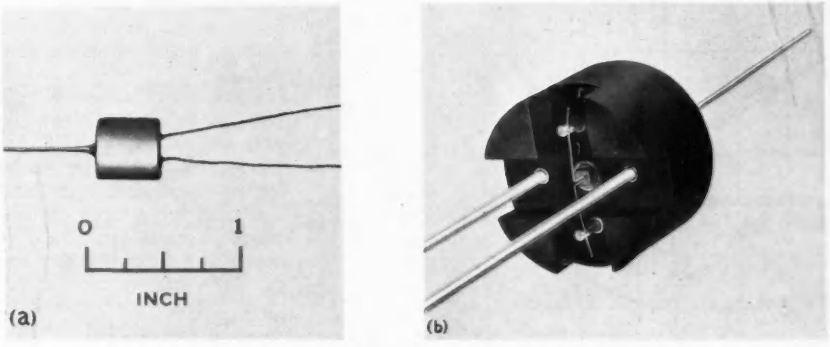


Fig. 2 (a) and (b).—General appearance, size and construction of the triode.

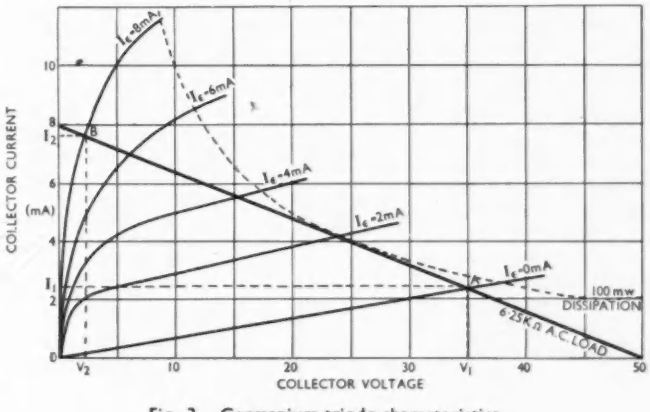


Fig. 3.—Germanium triode characteristics.

In the case of the thermionic triode, the quiescent anode dissipation is approaching zero, and the power output is 70 mW for the conditions assumed.

It will be apparent that, when used in a conventional way, the maximum output of the germanium triode is limited to some 20 mW by virtue of the H.T. limitations imposed by the low collector dissipation rating. The vacuum tube, however, runs at only a very small fraction of its maximum anode dissipation of 2·5 watts, for a power output of 70 mW (obtainable from a valve not designed as a power amplifier).

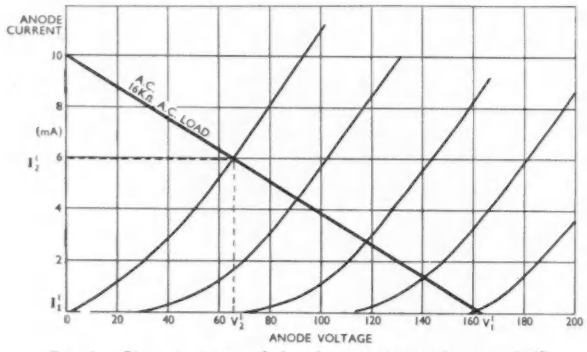


Fig. 4.—Characteristics of the thermionic triode, type L.63.

When used in this way, the crystal triode is very inefficient compared with a thermionic triode, and a new approach is required if it is to prove useful as a power amplifier. The two main requirements are :

(*a*) A system of operation providing low collector dissipation in the quiescent condition which will allow the use of higher supply voltage.

(*b*) A type of power supply with poor regulation so that the quiescent collector dissipation is maintained well within the maximum rating.

If instead of operating with zero bias the emitter is given a large positive bias, then with a resistive supply to the collector, the quiescent point would be point *B* (fig. 3), where the collector voltage is low and collector current relatively high. Under these conditions, the collector dissipation is given by $V_2I_2=22$ mW, which is approximately one quarter of that dissipation when the triode is used in a conventional circuit. Thus condition (*a*) is satisfied.

Requirement (*b*) can be met by using a resistive load of value equal to the A.C. load shown in fig. 3, which will ensure that the collector dissipation is not exceeded. However, in an output stage feeding a loudspeaker, an output transformer is required for matching to the low impedance speaker. It thus becomes necessary to run the transformer in parallel with the collector feed resistance. A blocking condenser will, however, be required in series with the transformer in this case to avoid shunting the resistor at D.C.

Combining these features, it is possible to evolve a modified push-pull output circuit for germanium triodes in which the output transformer is connected in parallel with the collector supply resistors. The triode emitters are biased positively, permitting a much larger voltage and current swing at the collectors for a given collector dissipation as compared with the conventional circuit. A simple circuit incorporating the above ideas is shown in fig. 5.

(4) THE CONCEPT OF DUALITY.

If the characteristics of the crystal triode and thermionic triode in figs. 3 and 4 respectively are compared, it will be noticed that those of the crystal triode would be very similar to those of the thermionic triode if collector current were interchanged with anode voltage, collector voltage with anode current, and emitter current with grid voltage.

In fact, the crystal triode is the approximate dual of the thermionic triode. This concept has been developed at some length by Raisbeck[2], who has shown how it is possible to deduce suitable circuits for use with crystal triodes by deriving the dual of the thermionic valve circuit.

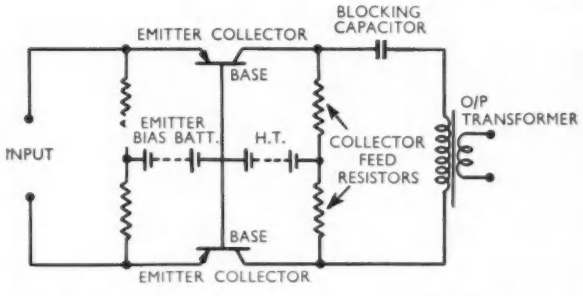


Fig. 5.—Modified crystal triode push-pull output stage.

Applying this principle to the push-pull amplifier it can be shown that the dual of the circuit of fig. 6 is that of fig. 7.

One important difference between these circuits is that in fig. 6 the D.C. supply is a constant voltage source, whereas in fig. 7 it is transformed to a constant current supply.

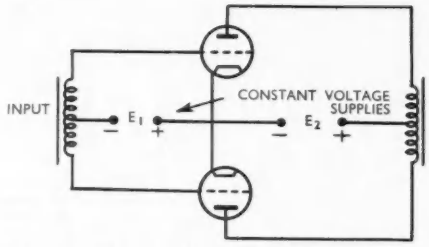


Fig. 6.—Class B push-pull thermionic valve circuit.

The simplest method to obtain a D.C. supply which will provide a constant current irrespective of the termination, is a high-resistance R in series with a high-voltage source E. If the circuit is completed by a resistance r, then

$$I=\frac{E}{R+r}\simeq\frac{E}{R}=\text{constant if } r\ll R \qquad (3)$$

In general, a compromise must be effected in the values of E and R, from the standpoint of economy.

(5) DETAILED DESCRIPTION OF THE PUSH-PULL CIRCUIT.

The complete circuit arrangement is shown in fig. 8, and may be seen to be a development of figs. 5 and 7. The constant current supply for each collector consists of a battery in series with an inductance L and a resistance R_p, the battery being common to the two. The use of an inductance enables a lower battery voltage to be used than with a resistance alone; also it makes the A.C. impedance of the source high to audio frequency so that its shunting effect on the load is less. Typical values for L and R_p are 20H and $2{\cdot}2K$ ohms respectively.

The bias current to the emitters is obtained from a battery in series with resistors R_e. A typical value for R_e is 1,000 ohms.

A single battery is used for both collector and emitter. This is earthed at the positive end and a tap corresponding to the emitter bias is connected to the base leads of the triodes. This arrangement enables the same battery to be used for the H.T. supply of preceding stages when necessary.

The output transformer is connected between the two collectors and the input transformer between the two emitters. Blocking condensers are connected in series with each transformer to avoid shunting the D.C. supplies.

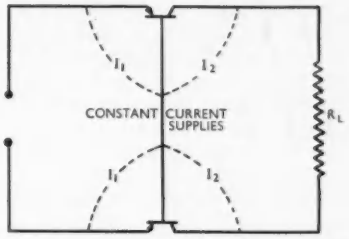


Fig. 7.—Dual of Class B push-pull amplifier.

(6) OPERATION OF THE CIRCUIT.

The operation of a thermionic triode push-pull amplifier is usually analysed by a graphical method.[3] In this method the anode current/anode voltage characteristics of the two triodes are plotted as shown in fig. 9. Here two families are combined on a common voltage axis, and both are symmetrically disposed with respect to the quiescent anode voltage (in the example taken, this is point θ). The load line is superimposed on the two families as shown.

A similar procedure can be applied to crystal triodes, but by virtue of the dual relationship between the crystal triode and the thermionic triode, the common axis is collector current.

The combined characteristics are shown in fig. 10. In the example taken, the quiescent

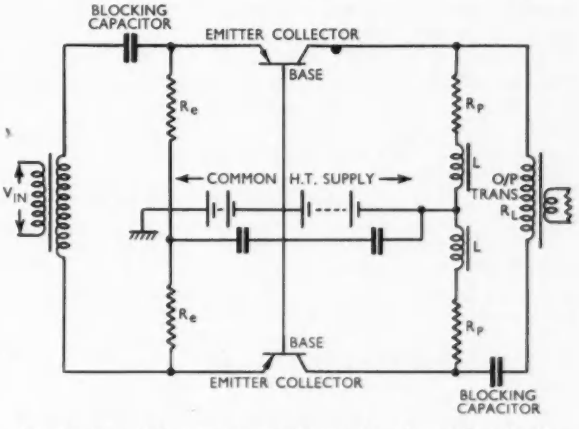


Fig. 8.—Practical germanium triode push-pull amplifier circuit.

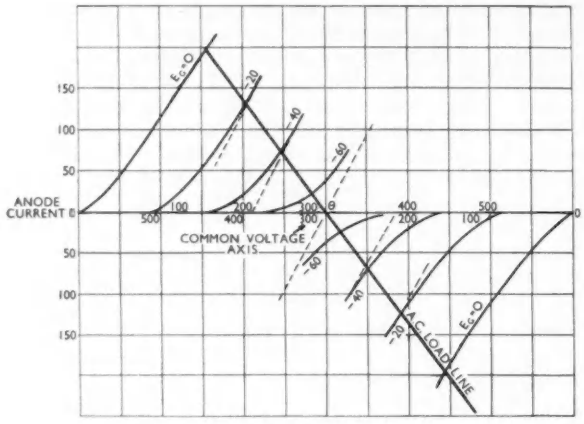


Fig. 9.—Combined characteristics for thermionic valve push-pull amplifier.

current is taken as approximately 10 mA in each triode, which is obtained when the emitter is biased to a current of approximately 10 mA. The collector dissipation of each triode in the quiescent condition is approximately 20 milliwatts.

As was noted in section (5), the D.C. conditions are determined by the value of the H.T. voltage and the resistances R_p, while the A.C. load is approximately R_L, if the shunting effect of the constant current network is small. Thus both D.C. and A.C. load lines are required to determine the triode operating conditions and power output from the curves of fig. 10. The D.C. load line is drawn through the quiescent point of fig. 10, to meet the voltage axis at a point corresponding to the battery voltage. The slope of the load line gives the value of the D.C. load. The A.C. load line similarly passes through the quiescent point. In fig. 10, two A.C. load lines have been drawn, corresponding to R_L greater or less than R_p.

For the case of R_L greater than R_p, the peak voltage appearing between collector and base (V^1) exceeds the battery voltage, due to the back e.m.f. appearing across the inductance L in series with the battery e.m.f.

The peak-to-peak voltage appearing across R_L is thus $2V^1$, and the power output is

$$P_{out} = \frac{(2V^1)^2}{8R_L} = \frac{(I^1 - I^{11})^2 R_L}{8} \quad (4)$$

The conditions prevailing during one half cycle of operation are indicated in figs. 11 and 12. Suppose each triode to be drawing a quiescent emitter and collector current of I_e and I_c respectively. If a sinusoidal input signal $I_e \sin \omega t$ is applied between the emitters, the emitter currents will be modified accordingly. Given a peak input current swing equal to the steady emitter bias, then on the negative half cycle, the emitter current of triode A in fig. 11, will swing to zero according to the relation $i_e = I_e (1\text{-}\sin \omega t)$ where $0 < \omega t < \pi$.

Assuming that distortion may be neglected, the collector current waveform in triode A will be indicated approximately by the relation $i_{c1} = I_c (1\text{-}\sin \omega t)$ as in fig. 12. However, the collector current is supplied from a network which presents a high impedance to A.C. and maintains a constant current I_c. Thus the A.C. component of I_c is negligible, so that on equating the currents at the junction C shown in fig. 11, $I_c = i_{c1} + i_2$, and on substituting for i_{c1}, then $i_2 = I_c \sin \omega t$,

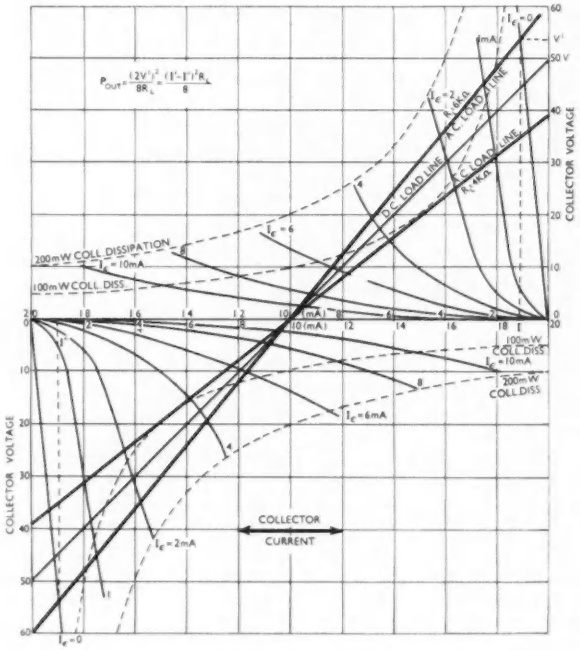


Fig. 10.—Push-pull output stage combined characteristics.

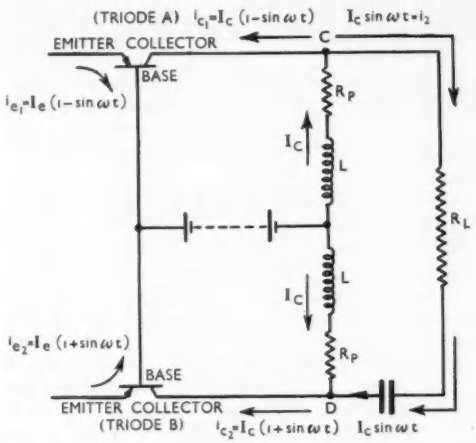


Fig. 11.—Paths followed by current during one half-cycle of operation.

which is a half sine wave positive pulse of current for $0<\omega t<\pi$, which passes through the load R_L.

At the lower triode *B*, the standing emitter bias will be increased by the positive going signal, so that the collector impedance will be very low and will present very little impedance to the load current $I_c \sin \omega t$.

For the next half cycle $\pi<\omega t<2\pi$, conditions will be reversed, with triode *B* biased to a high impedance condition. A current pulse is thus driven through the load in the reverse direction, and back through triode *A* which is then in a low impedance condition.

To summarise: the effect is that each triode is biased to a high impedance condition in turn, so that as the collector current falls, a current flows through the load such that the instantaneous sum of collector and load currents over a half cycle is constant and equal to that current supplied by the constant current network. The resultant current waveform through the load over a complete cycle is sinusoidal and has a peak-to-peak amplitude of approximately $2I_c$.

Fig. 13 shows the equivalent circuit, which is only strictly valid for small signal conditions. Here each generator drives current through the load in alternate half cycles of operation. The A.C. collector impedance is represented by the generator internal impedance r_o.

In the case of large signal conditions, while one triode is driving current through the load, the internal impedance of the other has fallen to a low value, due to its large positive emitter bias, and consequently little A.C. power is lost across it.

In this push-pull amplifier, the idle valve is biased to a low impedance which is in series

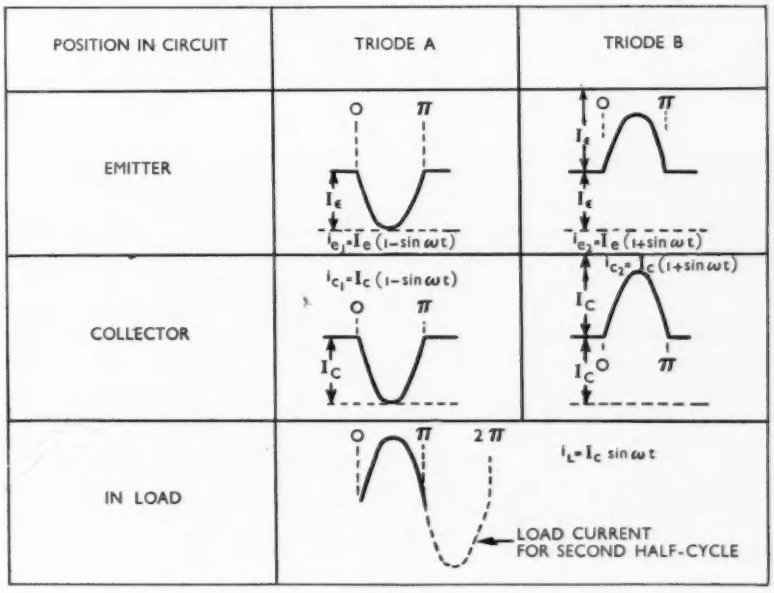


Fig. 12.—Current waveforms.

with the load, whereas in a thermionic valve push-pull circuit the idle valve is biased to a very high impedance which is effectively in parallel with the load.

(7) EXPERIMENTAL RESULTS.

In general, the operating conditions and power output which were indicated graphically in fig. 10, were obtained experimentally, allowance

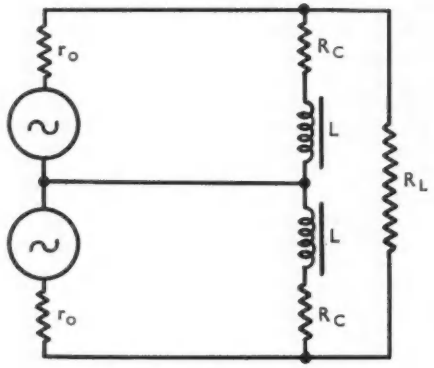


Fig. 13.—Equivalent circuit.

being made for the small amount of power dissipated in the idle crystal triode which is in series with the load. The power output was calculated from measurements of the voltage swing across a resistor which replaced the output transformer. For applications where a distorted waveform was acceptable, an output of over 0·5 watts was obtainable.

It will be observed from fig. 10 that the upper A.C. load line passes through a region of the graph in which the collector dissipation exceeds 100 mW, i.e. outside the area enclosed by the 100 mW curve and the axes. However, during that part of the cycle for which the triode emitter is biased positively, the collector dissipation is approximately equal to that under quiescent conditions and is considerably less than 100 mW, so that the mean collector dissipation is under 100 mW although the peak dissipation exceeds this value.

Experimental results over a number of hours, during which time the peak dissipation exceeded 100 mW for a small fraction of each cycle, have shown no deleterious effects on the germanium triodes.

Performance figures for the crystal triode push-pull amplifier are given in Table 1. The first set of results gives the maximum power output obtainable without exceeding the mean collector dissipation rating, or allowing the harmonic distortion to exceed 10 per cent. Under these conditions, the power ouput amounted to 420 milliwatts in a 5,000 Ω load. The emitter driving power was within the capabilities of a single germanium triode.

The second set of results was obtained under conditions for which the collector dissipation never exceeded 100 mW, and the power output was then 200 mW. This operating condition, for which the A.C. load line is tangential to the 100 mW dissipation curve, is illustrated on fig. 10.

(8) CONCLUSION.

A new push-pull crystal triode audio amplifier is described which is capable of delivering approximately 400 milliwatts output power from a pair of point contact crystal triodes. The maximum output is at present limited by the allowable maximum dissipation of 100 mW per triode.

The output power is of the order of ten times that obtainable from the triodes when used in a conventional push-pull circuit of the type usually used with thermionic triodes.

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TABLE 1.

Battery Voltage	Mean Collector Dissipation	Peak Collector Dissipation	Power Gain	Efficiency = Power Output / Power Consumption	Harmonic Distortion	Power Output
50V	100 mW	150 mW	12 db	28%	10%	420 mW
35V	65 mW	100 mW	13·5 db	21·5%	9%	200 mW

The Temper Mill Drives at the Trostre Works of the Steel Company of Wales

By J. P. HUGGARD, B.Sc., M.I.E.E., and S. A. G. EMMS, B.Sc.
Witton Engineering Works.

At Trostre Works, coiled steel strip from Abbey Works is converted into hot-dipped and electrolytically tinned plate. After cold reduction to finished gauge, the strip passes through one of two 2-stand temper mills which impart the desired mechanical properties and prepare the surface for the tinning operation which follows. These temper mills are the first in the country to operate at speeds of up to 4,000 ft. per minute. The application of the cascade control exciter system in conjunction with Ward-Leonard control for preserving the correct strip tension forms the subject of this article.

INTRODUCTORY.

REFERENCES have been made in previous issues of this Journal to much of the electrical plant and equipment which the G.E.C. has supplied to the Steel Company of Wales for the Margam, Abbey and Trostre Works. It will be recalled that the Abbey Works, which has now been in operation for two years, is devoted to the production of coiled strip, sheet and plates ranging from 27 in. to 74 in. in width and from 0·05 in. to 0·75 in. in thickness. At the Trostre Works, which was officially opened in October, 1952, hot-rolled steel from the Abbey Works is converted into both hot-dipped and electrolytically tinned plate in a wide variety of sizes, gauges and steel qualities.

The hot-rolled steel from Abbey Works is supplied to Trostre in coils weighing up to 15,000 lb., the maxima for gauge and width being 0·093 in. and 38 in. respectively. The coils are first processed in a continuous pickler to remove the hot mill scale and are then passed to a 5-stand tandem mill for cold reduction to the finished gauge. Two electrolytic cleaning lines are used for removing the palm oil employed in cold reduction, which would otherwise carbonise during the annealing process which follows. After annealing, skin passing is carried out in one of the two 2-stand temper mills which form the subject of this article. This operation imparts to the strip a surface suitable for tinning, and confers mechanical properties which are

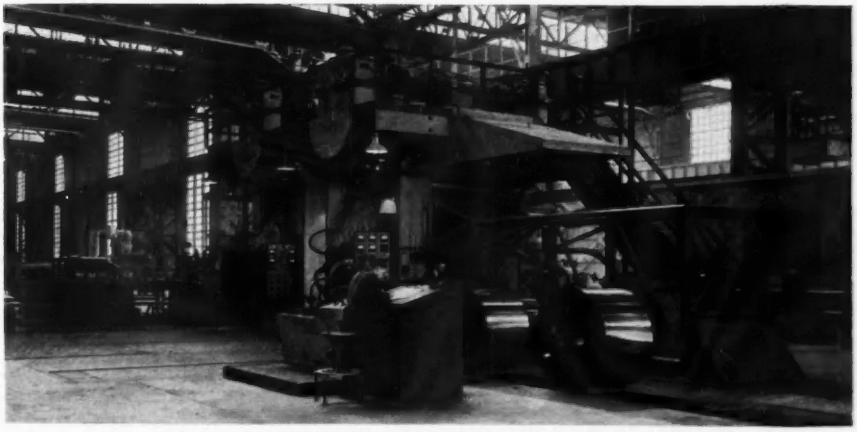


Fig. 1.—One of the two 2-stand Temper Mills at the Trostre Works, showing finished coils leaving the mill.

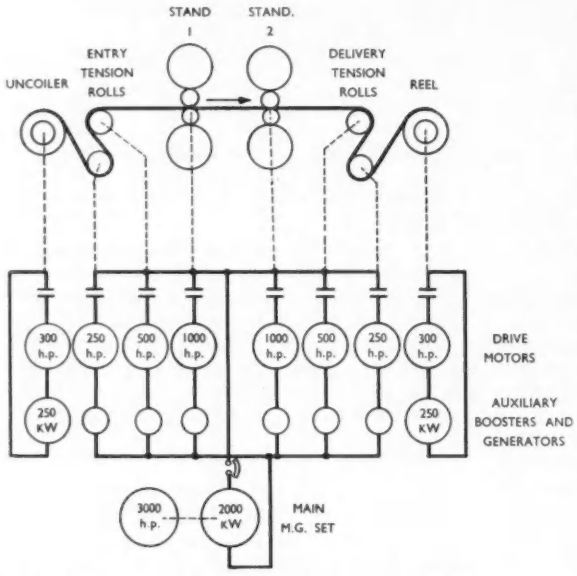


Fig. 2.—The arrangement of rolls and driving motors of a complete Temper Mill.

adjusted to suit the purpose for which the tinplate is intended. After temper rolling, coils intended for hot-dipped tinning pass through coil cut-up lines where they are sheared to the final size before entering the tinning bay. Coils intended for electro-tinning are side-trimmed on coil preparatory lines before passing to the electrolytic tinning lines.

2-STAND TEMPER MILLS.

Temper rolling of the steel strip is carried out in two 2-stand temper mills for which the G.E.C. supplied almost the whole of the electrical plant and control gear. The consulting engineers for the contract were McLellan & Partners and it is of interest to note that these are the first temper mills to operate in this country at speeds up to 4,000 ft. per minute. A general view of No. 1 mill is shown in fig. 1. The two mills are identical, the work rolls of each being 18 in. in diameter and 48 in. wide, and the back-up rolls 53 in. in diameter and 47 in. wide. As the steel strip is in a very soft condition when it enters the temper mill, great care is necessary to prevent breakage, wrinkling or buckling, and for this reason each mill has been equipped with two pairs of separately-driven tension rolls. A diagram showing the arrangement of rolls and drives for one complete mill is shown in fig. 2.

Strip is paid off the uncoiler drum at constant tension, and runs over the two entry tension rolls before entering No. 1 stand. The function of the entry tension rolls is to increase the tension to a very high value before the strip enters the stand, as if the strip were subjected to this tension when leaving the uncoiler, damage might occur. After passing through both stands of the mill and round the delivery tension rolls, it is finally re-coiled on the reel. The strip is subjected to a combination of high pressure and longitudinal tension as it passes through the stand, and the various physical properties and degrees of temper and finish which can be imparted by the tempering process are controlled by the tension and pressure which is applied, and by the roll surface. The operation reduces the thickness of the strip by an amount ranging from $\frac{1}{2}$ per cent to 4 per cent.

For tinplate intended for deep drawing, the extension is just sufficient to impart to the strip a close surface suitable for tinning ; at the other end of the range, for can body stock, shot-blasted rolls are employed in the first stand to increase the surface work hardening.

TABLE 1.

MOTORS FOR THE TEMPER MILL DRIVE.

Drive	No. of Motors	Horse-power	Volts	Speed r.p.m.
Main Drives for Stand 1 and 2	2	1,000	0/500	700/950
Top tension rolls, entry and delivery	2	500	0/500	735/1100
Bottom tension rolls, entry and delivery ..	2	250	0/500	735/1100
Uncoiler	1	300	0/500	185/835
Reel	1	300	0/500	185/835

ELECTRICAL PLANT.

Each mill is provided with 2-1,000 h.p. motors for the main stand drives, and six motors totalling 2,100 h.p. for the tension roll, uncoiler and reel drives. Ward-Leonard control in conjunction with the G.E.C. cascade control exciter system is used for both main and auxiliary drives, and the D.C. power supplies for the motors and control circuits are obtained from nine motor-generator, booster and cascade control exciter sets. Details of the various motors which comprise a complete mill drive are given in Table 1.

The D.C. supply for the main stand and tension roll motors is obtained from a 2,000 kW motor-generator set which is driven at 500 r.p.m. by a 3,000 h.p., 11 kV synchronous motor, while a 500 kW auxiliary motor-generator set driven at 1,000 r.p.m. by a 500 h.p., 3·3 kV synchronous motor provides the D.C. supply for the uncoiler and reel motors. The booster motor-generator set comprises six D.C. generators with outputs ranging from 21 to 67·5 kW. Each of these machines is connected in series with its corresponding stand or tension roll motor, and the set is driven at 970 r.p.m. by a 250 h.p., 3·3 kV squirrel cage motor. In addition to these three motor-generator sets six smaller sets are installed to provide supplies for the excitation and control of the mill motors and their associated generators.

The arrangement of the drives of No. 1 mill is shown in fig. 3. The two main stand motors and the two 500 h.p. top tension roll motors are grouped at the rear of the mill, the 1,000 h.p. machines being mounted at floor level and the smaller machines on raised plinths. The two 250 h.p. bottom tension roll motors are mounted in pits and are directly underneath the driving shafts of the top tension rolls. The uncoiler motor, which can be seen in fig. 1, is at the front of the mill, and the reel motor (not shown) is at the rear of the mill on the exit side. All motors are forced-ventilated, the air supplies being derived from separately driven fans mounted in a basement below the mill. For the two 1,000 h.p. machines closed air circuit cooling is employed, though provision has been made for some of the air to be exhausted to atmosphere if required. The cooling air for the smaller machines is exhausted to atmosphere. All the motors associated with the mill drives are equipped with thermostats for operating bearing temperature alarm and ventilation alarm circuits.

The 2,000 kW motor-generator set which supplies power to the main stand and tension roll motors is shown in fig. 4. The synchronous driving motor is provided with closed-air-circuit

Fig. 3.—The rear of No. 1 Temper Mill, showing the two 1,000 h.p. main mill motors and the two 500 h.p. top tension roll motors.

cooling, and with control gear which enables either reactor or direct-to-line starting to be employed. The booster set for the stand and tension roll motors is housed, together with the auxiliary motor-generator set for the uncoiler and reel motors and a 120 h.p. constant voltage exciter set, in a substation adjacent to the mill (fig. 5).

As the mill floor at Trostre is some 14 ft. above the original ground level, and is supported by reinforced concrete columns, there are basements extending under the whole floor area, and these have been used as electrical substations and control rooms. The main control set and the various cascade exciter sets have all been accommodated in basements and a typical group of cascade sets used for the uncoiler and reel drives is shown in fig. 6.

SWITCHGEAR.

The mill is controlled from three cabinets which are hinged to the main stands and contain the necessary instruments, controllers, regulators and indicating lamps. With the exception of these cabinets the whole of the switchgear for the mill is housed in the basement. The main switchboard, part of which is shown in fig. 7, is of the flatback contactor type which has been used throughout the Abbey and Trostre Works. The alarm panel is a single cubicle of pressed-steel construction, and a four-section cubicle of similar design has been used to house the resistors associated with the various control circuits. The alarm and resistor cubicles are shown in fig. 8.

The starting equipment for the driving motor of the main motor-generator set, which consists of an oil-immersed reactor and a short-circuiting breaker, is housed in other compartments of the basement together with the 3·3 kV circuit breakers controlling the motors of the reel generator and booster motor-generator sets.

METHOD OF CONTROL.

An essential requirement of the control scheme is that, irrespective of differences in the loads imposed on the two stand motors, their preset speed ratio must be maintained during acceleration and deceleration of the mill. Similarly, each pair of tension rolls is controlled so that the tension between them and the adjacent stands is maintained at the preset value throughout the acceleration and deceleration periods.

The equipment is so designed that the time taken to accelerate the mill from rest to full speed can be varied from 12 to 20 seconds, while the time required for stopping the mill from full speed can be adjusted between the limits of 5 and 20 seconds. Regenerative braking is normally employed to stop the mill, but a single step of

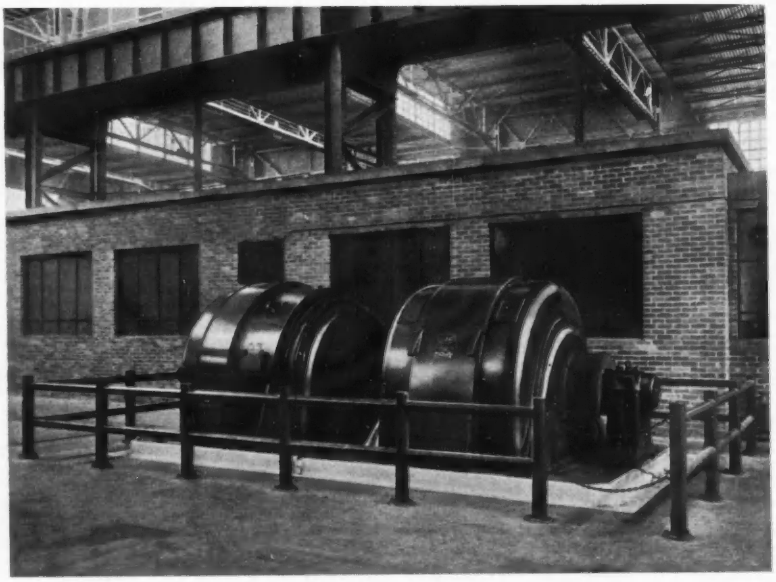


Fig. 4.—2,000 kW, 500 volt, motor-generator set for supplying power to the main stand and tension roll motors.

Fig. 5.—The substation for No. 1 Temper Mill, showing the 500 h.p. auxiliary motor-generator set, the 250 h.p. booster set and the constant voltage exciter set.

dynamic braking is provided to meet emergency conditions. The speed of the mill as a whole is varied by controlling the voltage of the generators of the motor generator sets, operation of the "thread" or "run" buttons on the control cabinet causing the mill speed to change to that selected. A "hold" button is provided to enable the mill speed to be maintained at any intermediate value. A further button known as "stand slow-down" causes a slight decrease in the speed of the first stand thus enabling loops which may be formed during threading to be removed. This speed returns to its previous value as soon as the button is released, and the control does not function at running speeds.

In order to preserve the correct tension in the strip as it passes through the mill, special control exciters, which are rapid-response machines of high amplification, are used for regulating the output of both the main and the auxiliary motor-generators, and for each of the motors driving the stands, tension rolls, uncoiler and reel.

The stand motors are fundamentally speed-controlled, with an overriding tension control which is actuated from a tensiometer roll by means of an electronic amplifier. The tension roll, uncoiler and reel motors are fundamentally current-controlled, and electronic amplifiers are used only to provide accurate accelerating and retarding torques.

To ensure that the speeds of the stand and tension roll motors follow closely the main generator voltage, boosters are provided to compensate for the resistance drop in the motors, and for changes in the diameters of the rolls.

Automatic control of the tension between the stands is provided by means of the tensiometer roll which supplies a correcting signal to an electronic amplifier from which two of the fields of the pilot control exciter for the first stand drive are energised. Provision is also made for manual control of the strip tension between the two stands.

As the strip passes from the uncoiler to the entry tension rolls and from the delivery tension rolls to the reel, constant tension is ensured under steady speed conditions by controlling

Fig. 6.—Two seven-machine control exciter sets for the uncoiler and reel drives in the basement of the Temper Mill.

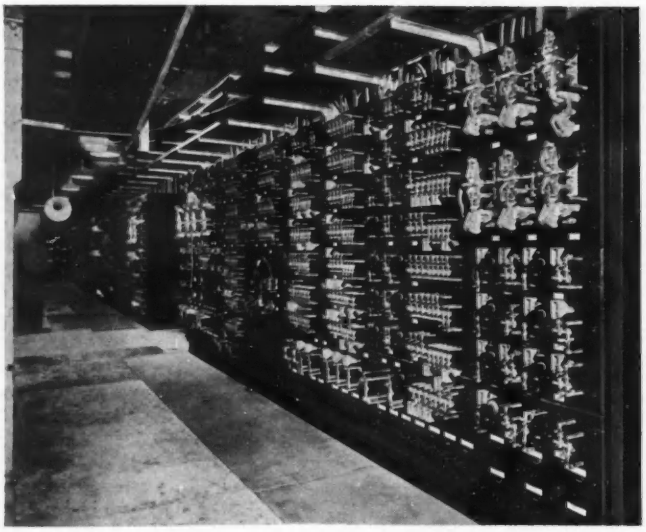


Fig. 7.—The main contactor switchboard for No. 1 Temper Mill.

Speed control is effected by varying the generator voltage as shown in the simplified diagram (fig. 10). A motor-driven master regulator *RM* is connected across the constant voltage busbars and the variable voltage thus derived serves as a reference voltage. The main generator field winding *GF* is excited from the output machine *ME*1 of the control exciter set. The pilot machine *PE*1 of this set is provided with two control field windings *A* and *D* (the stability windings of *PE*1 have been omitted from the diagram for clarity). Field *A* is energised from the reference voltage bars, and field *D*, which opposes *A*, from the armature of the main generator. Thus at any moment the main generator excitation is proportional to the difference between the reference voltage and the generator voltage. The generator excitation is thus automatically adjusted to maintain the generator voltage at a value proportional to the reference voltage.

The reference voltage is varied by means of the motor-driven regulator *RM* to maintain a pre-selected armature current in the motor while varying its excitation, and consequently its torque, automatically in proportion to the reel diameter. During periods of acceleration or deceleration, constant tension is preserved by increasing or decreasing the generator voltage to vary the current and torque of the driving motor, the change in torque taking into account the rate of change in speed and the change in the inertia of the reel. The control is such that stalled tension may be maintained when strip is in the mill at standstill. This can be released as desired.

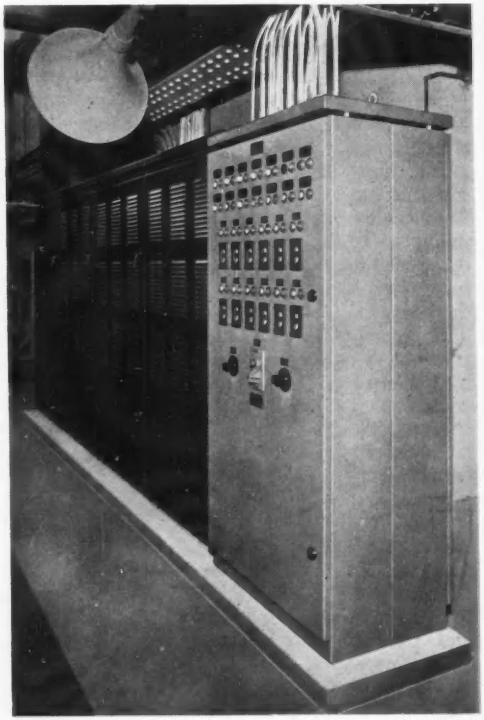


Fig. 8.—The alarm and resistor cubicles in the basement of No. 1 Temper Mill.

DETAILS OF CONTROL SCHEME.

Mill Stands.

A simplified schematic diagram of the connections for the two stand drives is shown in fig. 9. In the control of the mill the speed of No. 2 stand driving motor *M*5 is treated as the "master" for all the remaining drives. This motor is excited from the constant voltage line via a setting resistor *R*5, and a booster *B*5 is included in the armature circuit to ensure that the speed of the motor will be closely proportional to the voltage of generator *G*1, and will not be affected by the resistance drop in the armature. The booster *B*5 is excited from a two-field pilot exciter *ME*5, which has a pattern field *A* connected across the compoles of motor *M*5, and a balancing field *B* connected across the booster.

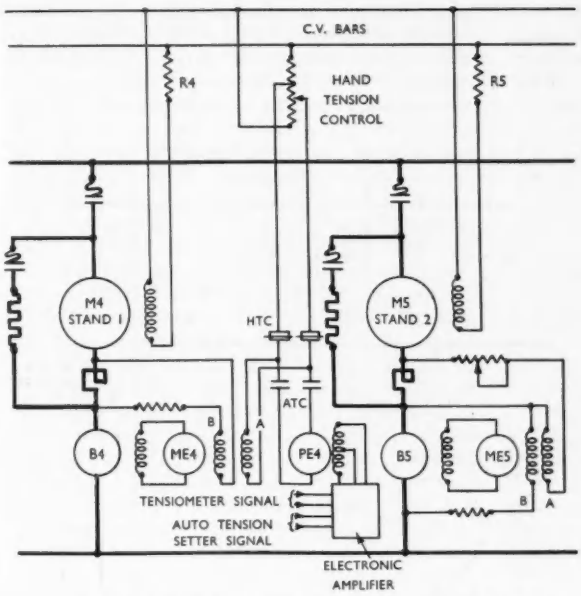


Fig. 9.—Simplified diagram of control for stands 1 and 2.

tional to the difference between these windings, and the system is so designed that a small difference is sufficient to develop a considerable voltage change in the main generator voltage. The generator voltage thus reflects the reference voltage closely at all times, even when the reference voltage is changing rapidly, as when starting or stopping.

The motor *RP*, which drives the regulator *RM* controlling the reference voltage, is actuated by a small Ward-Leonard generator *G5*, an arrangement which allows ready alteration of the acceleration and deceleration times. Another advantage of the Ward-Leonard drive is that, by suitably grading the master regulator, the rate of rise of main generator voltage is made proportional to the speed of the regulator motor *RP*, which in turn is proportional to the voltage across its armature. This voltage thus provides a very convenient acceleration-compensating signal for the tension roll drives.

The speed controls at the delivery cabinets are arranged so that "thread" and "run" speeds may be pre-selected there, the motion of the master regulator *RM* being automatically arrested at the required voltage. A "hold" button allows the motion of the regulator to be stopped at any intermediate point in either direction of travel. Pressure of any "stop" button will cause the master regulator to run back to "zero" at high speed, rapidly reducing the mill speed by regenerative braking. Finally, at "zero" with the strip tension released the suicide connections are momentarily applied to the main generator, and line contactors are opened.

"Inching" of main stands and tension rolls is effected from inching controllers on the cabinets which close the "forward" or "reverse" inching contactors in the generator pilot exciter field *A*, thus applying a low excitation in the direction required. A small regulator *RI* is provided so that the inch speed may be adjusted.

The control of stand 1 is similar to that of stand 2, with the addition of tension control of the strip between the stands. To provide this, the booster *B4* (fig. 9) is excited from a control exciter set whose pilot machine *PE4* is arranged to amplify, in conjunction with an electronic amplifier, a signal received from the tensiometer roll. A changeover switch enables hand tension control to be obtained by the excitation of winding *A* of *ME4*. A second field winding *B* on exciter *ME4* is connected across the compoles of the main motor and provides a component of booster excitation to compensate for resistance drop, as in the case of stand 2. The booster thus performs the two functions of tension control and resistance-drop compensation, and the range of excitation provided throughout is adequate to deal with the maximum specified difference in roll diameter.

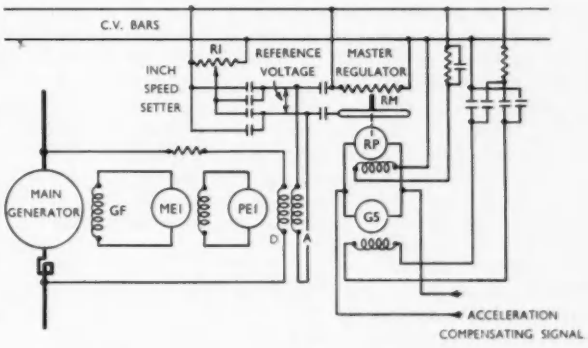


Fig. 10.—Simplified diagram of main generator control.

TENSION ROLLS.

Similar control arrangements have been adopted for both entry and delivery sections; the simplified diagram for a single roll is shown in fig. 11. The motor *M*2, which drives the tension roll, is separately excited from the constant voltage line, the circuit being provided with the necessary trimming resistor *R*2. The motor has in its armature circuit a booster which is excited from a control exciter set, and the pilot machine *PE*2 of this set has three control windings, *A*, *D* and *E*, the functions of which are described below.

D is a current-excited winding connected across the motor compoles.

A is a " tension-setting " winding connected to the constant-voltage line, through a " tension-setting " regulator *RT*, which is ganged to a similar regulator for the associated tension roll. In the case of the top tension rolls, this circuit also includes a potentiometer which acts as a tension ratio adjuster which varies the voltage fed to the tension-setting field of the top rolls in relation to that fed to the tension-setting field of the bottom rolls. The tension-setting winding carries a current which is determined by the position of the tension-setting regulator, and which is balanced by the current signal in winding *D*. The excitation imposed on the booster is determined by the difference between these two excitations and the system is so designed that a small difference applies a powerful signal to the booster field. Thus the roll motor armature current is held closely to the value pre-selected by the tension-setting regulator, and so long as the excitation of this motor is constant, constant torque and tension will result. During acceleration or deceleration an additional adjustment of armature current is needed to maintain constant tension. Since the inertia of the rolls is constant, and the acceleration of the mill approximately linear and proportional to the speed of the master regulator, a suitable signal is taken from the voltage across the master regulator pilot motor *RP*. This is applied to the exciter field winding *E* and brings about the desired increase or decrease in main armature current.

UNCOILER AND REEL.

A simplified schematic diagram of the reel equipment is shown in fig. 12. The circuit of the uncoiler equipment is basically similar to that of the reel though differing slightly in detail. Each motor is supplied from its own generator, which is controlled by a control exciter set. In both cases constant tension is produced under steady speed conditions by controlling the generator excitation to maintain a pre-selected armature current proportional to the desired strip tension, while the motor excitation is automatically varied to keep the e.m.f. induced in the motor armature constant for a constant strip speed as the coil builds up or unwinds, and proportional to the strip speed when the strip speed is varied.

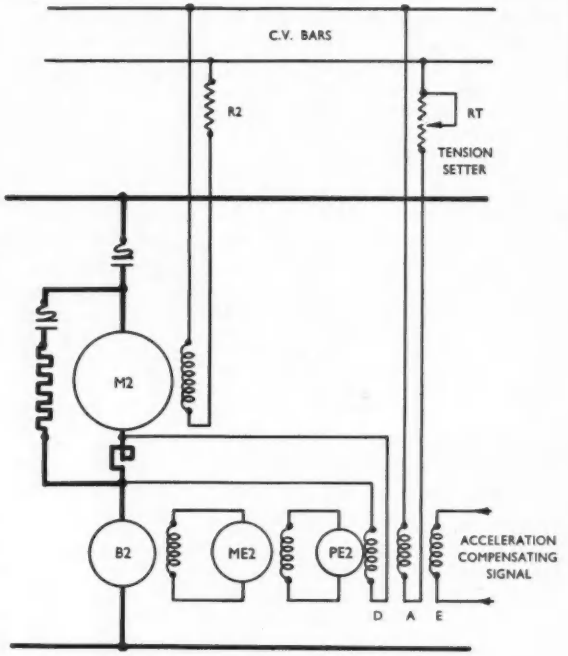


Fig. 11.—Simplified diagram of tension roll control.

During acceleration and deceleration the reel motor torque or current is automatically increased or decreased by an appropriate amount to deal with the rate of change of speed, and also with the large and varying inertia of the coil and reel, so that the strip tension does not alter.

Referring to fig. 12, it will be seen that pilot control exciter *PE*8 of the generator set is provided with two control field windings, of which *A* is excited by a signal derived from the saturable reactor *SR*.

There are two input signals to the saturable reactor: the first is proportional to the main armature current, and the second is derived from

the constant voltage supply via tension-setting regulator *RT*. The second signal, which raises the generator voltage and current, is, under running conditions, almost cancelled by the first signal. The output signal which excites winding *A* of *PE*8 is proportional to the difference between the input signals, so that any departure from the armature current pre-selected by the tension setter brings about an immediate correction in excitation. To effect the necessary adjustment in the main armature current required during acceleration or deceleration, a third signal is taken from the reference voltage bars and is applied to a differentiating transformer, the output of which is thus proportional to the rate of change of strip speed. This signal is passed to an electronic amplifier. At a suitable stage in the amplifier the signal is modulated according to the varying coil diameter, and hence inertia, of the coil and reel, and adjustment by means of contactors allows additional compensation for 3 stages of strip width. The signal from the amplifier is thus proportional to the rate of change of speed and is suitably modified to take account of the varying inertia of the coil and reel. This signal is passed from the amplifier to a third control winding on the saturable reactor *SR*. This third control winding modifies the effect of the tension setting winding and thus either increases or decreases the reel motor armature current by the appropriate amount.

The reel motor is furnished with two field windings of which the first (*MF*1) is excited from the constant voltage line via the trimming resistor *R*8. This winding is designed to provide the excitation corresponding to full speed with empty reel, i.e. the maximum service speed. The second winding *MF*2 is designed to cover the range between full and empty reel diameters, with a small allowance for regulating purposes. *MF*2 is supplied from a control-exciter set whose pilot machine *PE*9 is excited in proportion to the reel build up.

The reel control-exciter set also includes two small generators *G*1, *G*2, so arranged that their e.m.f.'s are proportional to the armature counter-e.m.f.'s of stand 2 driving motor *M*5, and the reel motor respectively. To accomplish this, each of these generators has two field windings. One is connected across the armature of its associated mill motor and generates an e.m.f. proportional to the mill motor armature voltage ; the second field winding is excited by the voltage across the motor compoles, and generates an e.m.f. proportional to the voltage drop in the mill motor armature. Thus the total generator excitation gives in each case an e.m.f. proportional to the back e.m.f. of the mill motor. The voltage of *G*1 is thus proportional to the back e.m.f. of the stand 2 motor, while the voltage of *G*2 is proportional to the back e.m.f. of the reel motor.

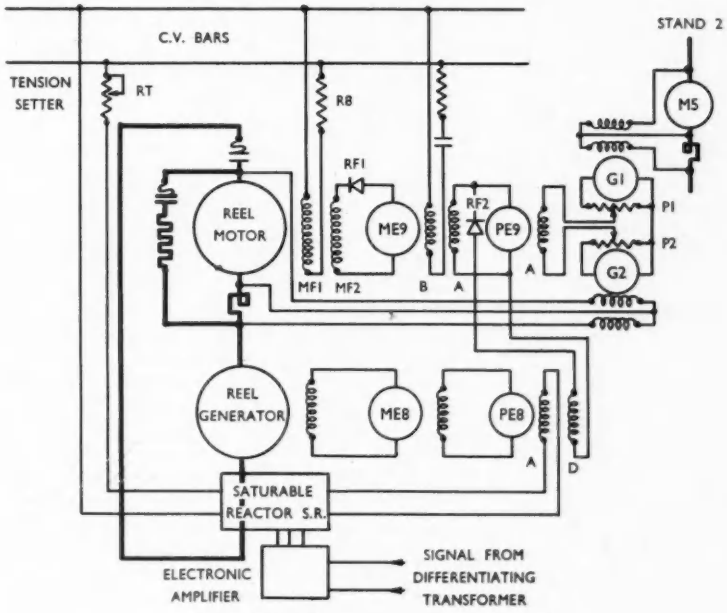


Fig. 12.—Simplified diagram of reel control.

These voltages are balanced against each other through the potentiometers *P*1 and *P*2 and the difference is applied to the field winding *A* of the reel motor pilot exciter *PE*9. This voltage difference is enough to alter the excitation of the reel motor field winding *MF*2 so that the total excitation produced by *MF*1 and *MF*2 generates a back e.m.f. in the reel motor armature which is at all times proportional to the back e.m.f. of the stand 2 driving motor, that is to strip speed. As the

coil builds up and the reel diameter increases at constant strip speed, the speed of the reel motor progressively decreases, and its excitation is automatically increased so that the relationship between the back e.m.f. of the reel motor armature and the strip speed is correctly maintained.

With no strip in the mill, the reel will tend to overspeed. Should this occur, the voltage of *G*2 will exceed that of *G*1, thus reversing the polarity of the pilot exciter *PE*9. In order to prevent this reversal from reaching the reel motor field (and so accentuating the trouble by opposing *MF*1) a rectifier *RF*1 is included in the armature circuit of exciter *ME*9. When, under overspeed conditions, the polarity of *PE*9 is reversed, the field of the pilot exciter of the reel generator (winding *D* of *PE*8) will be energised via *RF*2, thus limiting the speed rise to approximately 20 per cent above thread speed. To cater for broken strip at speeds above " thread ", a relay across the motor field pilot exciter *PE*9 detects the reversal in voltage and quickly causes the whole mill to stop. Inching in either direction is effected by applying a small reversible field to the reel generator main exciter *ME*8 by means of inching controllers on the cabinets.

Since the reel generator will maintain the armature current at the prescribed value, it will automatically maintain tension in the standstill or stalled condition. This stalled tension is usually reduced to 15/40 per cent of the full value by inserting resistance in series with the reel tension setter. At the same time the field winding *MF*2 of the reel motor is excited by means of a special auxiliary field winding *B* on exciter *ME*9, since field winding *A* is unexcited because the reel and stand motors are at rest. This field winding *B*, which is excited from the constant voltage busbars, is also used during " inching " of the reel motor.

At standstill stalled tension for the tension roll motors is obtained by transferring the tension-setting fields of their respective boosters from the " running tension setter " to the " stalled tension setter ".

The uncoiler equipment maintains constant tension while running at normal mill speeds, in the manner already described for the reel equipment. Some modifications, however, are necessary for threading conditions. Under normal starting conditions, with a full coil on the uncoiler, the motor field is at full strength. The motor field has two windings, one of which provides minimum excitation for the empty reel condition, and the other a variable excitation from the output machine of the exciter set. A rectifier is included in the latter circuit so that the second field can never be reversed to oppose the first. The main exciter also has two fields : the first provides the normal control via two build-up generators and the pilot exciter as on the reel, while the second provides the excitation required for starting, since at very low speeds the first field is practically unexcited.

At starting, the main exciter of the uncoiler generator receives a low excitation from the constant voltage bars, thus providing a low motor speed for paying off strip. The actual speed can be adjusted by the operator to suit the various sizes of coil. Once the strip has reached the stands tension can be applied and the control is changed to the normal tension control.

Acceleration compensation is achieved by modifying the tension reference on the saturable reactor with the output of an electronic amplifier, as on the reel gear, and stalled tension is also arranged in a similar manner to that described for the reel.

ACKNOWLEDGMENT.

The authors desire to make acknowledgment to the Steel Company of Wales for their courtesy in granting permission for the publication of the foregoing information and illustrations.

Speed Control of A.C. Winders

By E. FRIEDLANDER, Dr. Ing., M.I.E.E., Consulting Engineer, Witton
and S. A. G. EMMS, B.Sc., and C. A. MAER, Witton Engineering Works.

INTRODUCTION.

FOR ease of operation, it is generally recognised that the ideal system of control for any electric winder is that which provides a direct relationship between the steady rope speed and the position of the driver's power lever, while at the same time affording complete protection against the occurrence of excessive torque irrespective of the manner in which the power lever is operated.

Prior to the introduction of the G.E.C. system of speed control, no control schemes have been available for A.C. winders whereby these fundamental requirements are fully and satisfactorily met. They are, however, completely satisfied by the scheme described herein. Driving, dynamic braking and reverse-current braking are obtained by a power lever operating in a single slot, and where load conditions permit, regenerative braking is available at maximum winder speed. Thus, from the driver's point of view, the operation of an A.C. winder with this system of control closely simulates that long established for D.C. equipments.

So long as the winder motor is running at the pre-selected speed, the control gear is in a state of equilibrium, but any change disturbs this state and the speed is automatically adjusted until balance is re-established.

A quick movement of the lever from " stop " to any position will cause the maximum safe torque to be developed by the motor until the selected speed is reached, after which this speed will be maintained irrespective of load, dynamic braking being applied automatically if the load calls for it.

Similarly, a quick movement of the lever from " full speed " to an intermediate position will apply dynamic braking until the selected speed is reached, after which this speed will be maintained automatically by driving or braking as needed. Movement of the lever from " forward " through " stop " to " reverse ", or vice versa, will apply reverse-current braking.

ADVANTAGES OF THE SCHEME.

The scheme developed by the G.E.C. possesses many advantages of which the most outstanding are :

(*a*) It provides the ideal driving characteristics for A.C. winders, as outlined above.
(*b*) Complete safety independent of the action of the driver.
(*c*) Retarding cams, as used in the Ward-Leonard system, can be applied easily if considered desirable.
(*d*) Automatic (cyclic) winding can be provided with relatively little additional gear.
(*e*) Saving of energy arising from the use of dynamic and regenerative braking.
(*f*) Heating of the winder motor is minimised, since the system is self-adjusting to optimum conditions at all times.
(*g*) Reduced maintenance owing to greatly reduced wear of the mechanical brakes.

DESCRIPTION OF THE SCHEME.

The scheme can be understood most readily by considering it under four main headings.

(1) The rotor control system, which automatically adjusts the resistance in the rotor circuit to the correct value for any conditions of speed and load.
(2) The speed-signalling system, which compares the speed selected by the driver with the actual speed at any moment and passes a suitable impulse or signal to (1).
(3) The excitation system.
(4) The working of the scheme as a whole.

THE ROTOR CONTROL SYSTEM.

When dynamic braking is applied to an induction motor by exciting its stator with direct current, and dissipating the energy generated by the rotor in a resistor, certain difficulties can arise.

(*a*) Under certain conditions the machine becomes unstable, and an increase of rotor speed results in reduced braking torque.
(*b*) The stator excitation may be too high,

coil builds up and the reel diameter increases at constant strip speed, the speed of the reel motor progressively decreases, and its excitation is automatically increased so that the relationship between the back e.m.f. of the reel motor armature and the strip speed is correctly maintained.

With no strip in the mill, the reel will tend to overspeed. Should this occur, the voltage of *G*2 will exceed that of *G*1, thus reversing the polarity of the pilot exciter *PE*9. In order to prevent this reversal from reaching the reel motor field (and so accentuating the trouble by opposing *MF*1) a rectifier *RF*1 is included in the armature circuit of exciter *ME*9. When, under overspeed conditions, the polarity of *PE*9 is reversed, the field of the pilot exciter of the reel generator (winding *D* of *PE*8) will be energised via *RF*2, thus limiting the speed rise to approximately 20 per cent above thread speed. To cater for broken strip at speeds above " thread ", a relay across the motor field pilot exciter *PE*9 detects the reversal in voltage and quickly causes the whole mill to stop. Inching in either direction is effected by applying a small reversible field to the reel generator main exciter *ME*8 by means of inching controllers on the cabinets.

Since the reel generator will maintain the armature current at the prescribed value, it will automatically maintain tension in the standstill or stalled condition. This stalled tension is usually reduced to 15/40 per cent of the full value by inserting resistance in series with the reel tension setter. At the same time the field winding *MF*2 of the reel motor is excited by means of a special auxiliary field winding *B* on exciter *ME*9, since field winding *A* is unexcited because the reel and stand motors are at rest. This field winding *B*, which is excited from the constant voltage busbars, is also used during " inching " of the reel motor.

At standstill stalled tension for the tension roll motors is obtained by transferring the tension-setting fields of their respective boosters from the " running tension setter " to the " stalled tension setter ".

The uncoiler equipment maintains constant tension while running at normal mill speeds, in the manner already described for the reel equipment. Some modifications, however, are necessary for threading conditions. Under normal starting conditions, with a full coil on the uncoiler, the motor field is at full strength. The motor field has two windings, one of which provides minimum excitation for the empty reel condition, and the other a variable excitation from the output machine of the exciter set. A rectifier is included in the latter circuit so that the second field can never be reversed to oppose the first. The main exciter also has two fields : the first provides the normal control via two build-up generators and the pilot exciter as on the reel, while the second provides the excitation required for starting, since at very low speeds the first field is practically unexcited.

At starting, the main exciter of the uncoiler generator receives a low excitation from the constant voltage bars, thus providing a low motor speed for paying off strip. The actual speed can be adjusted by the operator to suit the various sizes of coil. Once the strip has reached the stands tension can be applied and the control is changed to the normal tension control.

Acceleration compensation is achieved by modifying the tension reference on the saturable reactor with the output of an electronic amplifier, as on the reel gear, and stalled tension is also arranged in a similar manner to that described for the reel.

ACKNOWLEDGMENT.

The authors desire to make acknowledgment to the Steel Company of Wales for their courtesy in granting permission for the publication of the foregoing information and illustrations.

Speed Control of A.C. Winders

By E. FRIEDLANDER, Dr. Ing., M.I.E.E., Consulting Engineer, Witton
and S. A. G. EMMS, B.Sc., and C. A. MAER, Witton Engineering Works.

INTRODUCTION.

FOR ease of operation, it is generally recognised that the ideal system of control for any electric winder is that which provides a direct relationship between the steady rope speed and the position of the driver's power lever, while at the same time affording complete protection against the occurrence of excessive torque irrespective of the manner in which the power lever is operated.

Prior to the introduction of the G.E.C. system of speed control, no control schemes have been available for A.C. winders whereby these fundamental requirements are fully and satisfactorily met. They are, however, completely satisfied by the scheme described herein. Driving, dynamic braking and reverse-current braking are obtained by a power lever operating in a single slot, and where load conditions permit, regenerative braking is available at maximum winder speed. Thus, from the driver's point of view, the operation of an A.C. winder with this system of control closely simulates that long established for D.C. equipments.

So long as the winder motor is running at the pre-selected speed, the control gear is in a state of equilibrium, but any change disturbs this state and the speed is automatically adjusted until balance is re-established.

A quick movement of the lever from " stop " to any position will cause the maximum safe torque to be developed by the motor until the selected speed is reached, after which this speed will be maintained irrespective of load, dynamic braking being applied automatically if the load calls for it.

Similarly, a quick movement of the lever from " full speed " to an intermediate position will apply dynamic braking until the selected speed is reached, after which this speed will be maintained automatically by driving or braking as needed. Movement of the lever from " forward " through " stop " to " reverse ", or vice versa, will apply reverse-current braking.

ADVANTAGES OF THE SCHEME.

The scheme developed by the G.E.C. possesses many advantages of which the most outstanding are :

(*a*) It provides the ideal driving characteristics for A.C. winders, as outlined above.
(*b*) Complete safety independent of the action of the driver.
(*c*) Retarding cams, as used in the Ward-Leonard system, can be applied easily if considered desirable.
(*d*) Automatic (cyclic) winding can be provided with relatively little additional gear.
(*e*) Saving of energy arising from the use of dynamic and regenerative braking.
(*f*) Heating of the winder motor is minimised, since the system is self-adjusting to optimum conditions at all times.
(*g*) Reduced maintenance owing to greatly reduced wear of the mechanical brakes.

DESCRIPTION OF THE SCHEME.

The scheme can be understood most readily by considering it under four main headings.

(1) The rotor control system, which automatically adjusts the resistance in the rotor circuit to the correct value for any conditions of speed and load.
(2) The speed-signalling system, which compares the speed selected by the driver with the actual speed at any moment and passes a suitable impulse or signal to (1).
(3) The excitation system.
(4) The working of the scheme as a whole.

THE ROTOR CONTROL SYSTEM.

When dynamic braking is applied to an induction motor by exciting its stator with direct current, and dissipating the energy generated by the rotor in a resistor, certain difficulties can arise.

(*a*) Under certain conditions the machine becomes unstable, and an increase of rotor speed results in reduced braking torque.
(*b*) The stator excitation may be too high,

requiring unnecessary rotor resistance for a given torque and resulting in unnecessary heating.

Schemes have been evolved in which some rough co-ordination between excitation and resistance, usually involving a time-delay mechanism, together with special exciters, rectifiers and so forth, has been made in an attempt to overcome these difficulties.

The present scheme differs fundamentally from all these in that it takes full account of the electrical conditions in the rotor circuit during driving, braking or reverse-current braking, which must be satisfied in order to give optimum performance.

It can be shown* that, at a given excitation and speed, the maximum braking torque is developed when :

Rotor circuit resistance = speed $\times K_1$ (a constant).

A similar relationship for maximum torque when driving or plug-braking can be shown to be necessary at any given speed, namely :

Rotor circuit resistance = slip $\times K_2$ (a constant).

It will be evident that by adjusting K_1 and K_2 the maximum, or any chosen torque, may be maintained at optimum conditions.

In this scheme, therefore, the resistance in the rotor circuit is varied automatically so as to comply with the above conditions. This is effected through the action of an hydraulic servo mechanism by means of which the resistance in the rotor circuit is adjusted automatically to the optimum value at all times. The rotor resistor

* *G.E.C. Journal*, Vol. XVI, No. 4, October, 1949.

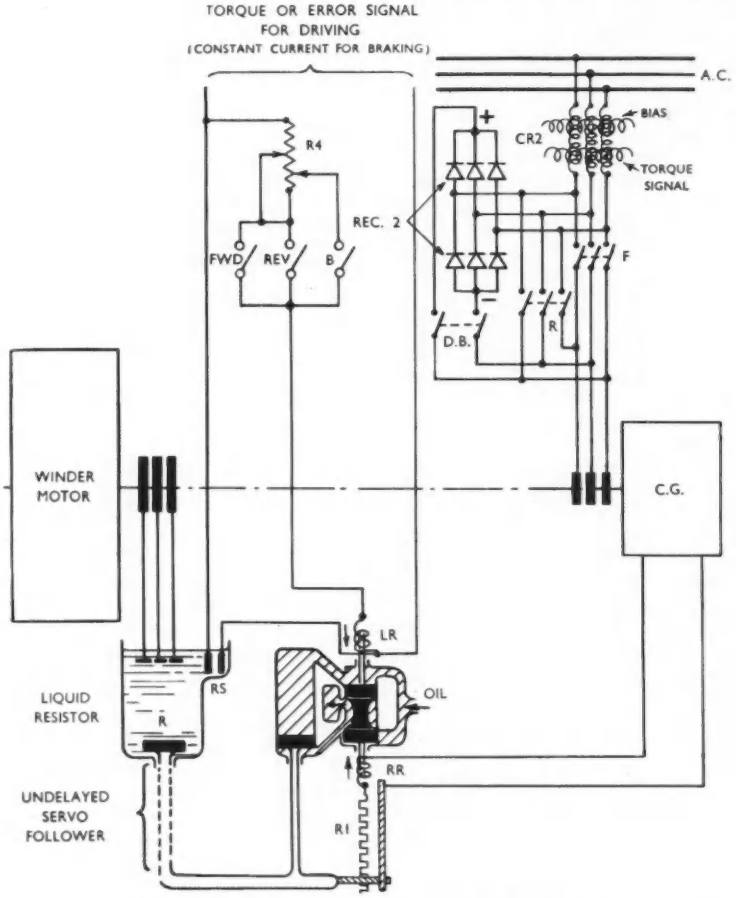


Fig. 1.—Schematic diagram of the rotor control system.

may take the form either of metallic grids or a liquid controller.

The basic elements are as shown in fig. 1. The rotor resistor R is varied by an hydraulic servo-mechanism, under the control of two opposing coils LR (" lower resistance ") and RR (" raise resistance "). The coil LR is energised by alternating current, the value of which is determined by the torque and speed signalling as described below. When driving, this current varies with the speed error in a ratio of about 2:1 ; when dynamic braking, this current is constant.

The coil RR, which opposes LR, is supplied from the stator or secondary winding of a control generator CG driven by the winder motor WM. Thus, at any given rotor or primary excitation of CG, the voltage across RR reflects that of the rotor of the main winder motor, and varies directly with the slip or speed.

The primary excitation of CG is derived from the controllable reactor $CR2$. For simplicity, this reactor, like others used in the scheme, is referred to as a magnetic amplifier because controllable reactors serve as the actual amplifying elements in any magnetic amplifier circuit. The magnetic amplifier $CR2$ is controlled by the speed-error signal in such a way that for zero or small errors the excitation of RR is high and decreases with increasing error in speed, i.e. the greater the speed error the smaller the excitation of RR. This reduction, however, is limited to a set value.

The total variation of torque in driving is controlled by a simultaneous variation of the LR current and the control generator voltage across RR, both of which are functions of the signal current but act in opposition to each other. The control generator voltage can vary in a ratio of about 1:6 at any speed, which, together with the variation of 1:2 of the current in the LR coil, gives a total torque control ratio of 1:12. On the other hand, when dynamic braking is used, the same total torque control ratio is achieved with a constant current in the LR coil, because the variation of torque with D.C. excitation is of the order of 2:1, so that the excitation control ratio of 1:6 is sufficient to give the required 1:12 total torque control ratio.

The variation of the LR coil excitation is kept to a minimum in order to preserve a high degree of sensitivity of the servo-regulator.

Also connected in the RR circuit is a variable resistor R_1, actuated by the servo-mechanism and arranged so that its value always reflects that of the rotor resistor R. As the frequency of the voltage V is that produced by the slip, it is very low at high speeds and to avoid pulsation of the hydraulic servo-gear, the whole RR circuit is made two-phase. Since the temperature coefficient of the metallic resistor R_1 is small while that of the liquid resistor R is large, some compensation must be made for the very considerable variation in R with temperature. This is effected by means of a small fixed liquid resistor RS, connected in parallel with the coil LR. This resistor is located in a pocket in the liquid controller and is therefore subject to the same temperature variation as R.

If the driver's lever is moved from " stop " (by more than 25 per cent of its travel) a fixed maximum A.C. excitation appears in the coil LR, while the control generator CG receives minimum excitation. Simultaneously the coil RR is excited by the equivalent of the rotor standstill volts. At this instant the coil RR is in series with the whole of R_1, so that a small current passes, an equivalent small current passing through R in the rotor circuit of the winder motor. Under these conditions the coil LR prevails and cuts out R_1 and R together. If, for the sake of argument, the mechanical brake has not been released, a point is reached where the reduction in R_1 is such that the increase in the current in RR is sufficient to produce a pull which balances that of LR. The operating valve then closes and the motion of the servo mechanism is arrested. The circuit resistances are so chosen that at this instant the motor is exerting its maximum torque. If the brake be now released, the winder motor will accelerate, and both its slipring volts and equivalent voltage V from the control generator will fall. The current in RR is accordingly reduced, and LR again takes control and opens the operating valve. Thus the servo resumes its motion and R and R_1 are further reduced so that the pulls exerted by RR and LR are kept very nearly in a state of balance.

From the foregoing it will be noted that during acceleration :

Ampere-turns in LR = Ampere-turns in RR + the constant weight effect.

Now ampere-turns in LR are constant during this period.

The ampere-turns in RR will be nearly constant so that the current in RR will be nearly constant, i.e.

$$\frac{V}{R_1} = K, \text{ or } R_1 = \frac{V}{K}$$

but V = per cent slip × rotor standstill volts V_1 (a constant)

$$\text{so } R_1 = \frac{\text{per cent slip} \times V_1}{K}$$

i.e. R_1 = slip × a constant K_2.

Now the winder rotor resistor R is proportional to R_1, just as the winder rotor voltage is proportional to V_1, and thus the fundamental requirement for constant torque performance, namely $R = K_2 \times$ slip, is fulfilled.

This relationship holds good for any value of slip and therefore covers reverse-current braking, when the slip exceeds 100 per cent. It will readily be understood that a similar argument may be developed for the conditions which apply during dynamic braking, the only difference being that in this case :

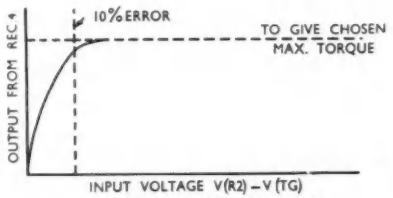
V = speed $\times$ (rotor volts at full speed and excitation) and hence—

R = speed $\times$ a constant K_1.

K_1 in this case varies with the D.C. excitation so that the fundamental requirement for optimum braking performance with minimum excitation is also met. The difference between K_2 and K_1 is effected (fig. 1) by adjusting the resistor R_4 in the LR circuit.

It will thus be appreciated that during acceleration or deceleration the rotor resistor R is adjusted automatically to ensure maximum safe torque output from the motor. As the required speed is approached, the speed-error signal diminishes, which in turn increases the excitation of the control generator, and hence its voltage V. At the same time the current in the LR coil is reduced. These changes alter the values of the constants K_1 or K_2 to give the correct electrical conditions for the winder

FIG. 2B



SATURATION CHARACTERISTIC

FIG. 2A

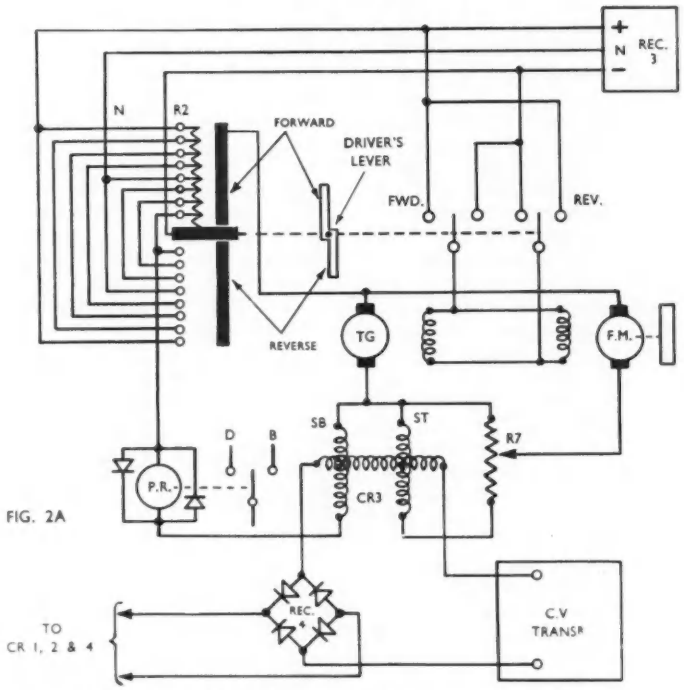


Fig. 2 (A and B).—Schematic diagram of the speed-signalling system.

motor at the torque demanded by the load. Variations in the load during the wind will cause only a slight speed variation which is, however, enough to adjust the value of K_1 or K_2 to correspond.

THE SPEED-SIGNALLING SYSTEM.

This is shown in simplified form in fig. 2(A). At " stop " the driver's lever is in the middle of a " gate " and its first lateral movement selects the direction of rotation of the motor. Further movement in either slot actuates a D.C. potentiometer R_2, by means of which a " pattern " or reference voltage is selected, which determines the final steady speed of the winder. This voltage is balanced against a voltage from the tachometer-generator *TG* through the speed-balancing winding *SB* of the magnetic amplifier *CR*3. This winding is in series with the polarised relay *PR* which determines whether the motor drives or brakes. Across the terminals of the tacho-generator *TG* is a small motor *FM* fitted with a flywheel, and connected in series with the stabilising winding *ST* of the magnetic amplifier *CR*3. Since the " pattern " voltage does not reverse with the movement of the driver's lever through " off ", provision is made whereby the lateral movement of this lever reverses the separately excited fields of *TG* and *FM*. Thus, if the " pattern " voltage exceeds that of the tacho-generator, a current will circulate through the speed-balancing winding *SB* of the magnetic amplifier *CR*3 and produce a corresponding output from the rectifier *Rec.* 4

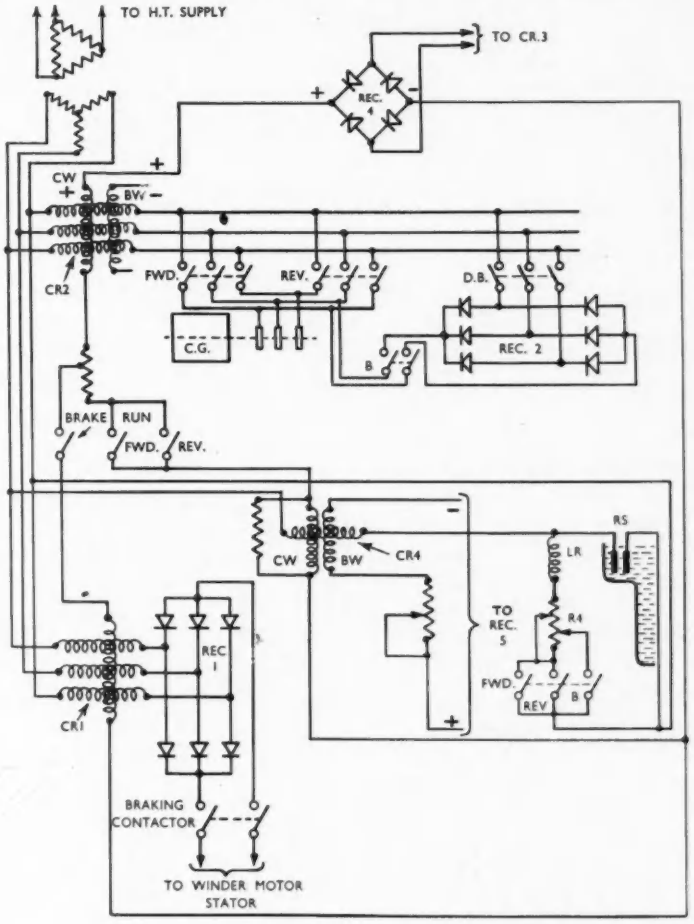


Fig. 3.—Schematic diagram of the excitation system.

which feeds the excitation circuits described below. At the same time the polarised relay *PR* sets up the circuits for driving. Similarly, if the tacho-generator voltage exceeds the " pattern " voltage, a current in the opposite sense will pass through *SB* and *PR*, and the polarised relay will set up the circuits for braking.

The potentiometer *R*2 is tapped in such a way that a residual pattern voltage is still present in the " stop " position to give a brake signal down to zero tacho-generator voltage. This ensures that maximum dynamic braking is available down to the lowest possible speed.

As the winder motor accelerates or decelerates in response to a change in the " pattern " voltage, the current through the flywheel motor *FM* varies in proportion to the rate of change. This current, circulating in the stabilising winding *ST* of the magnetic amplifier *CR*3, opposes the effect of the speed-balancing winding *SB* and so provides the " negative feed-back " necessary for stability. A resistor *R*7, connected across the winding *ST*, enables this feed-back to be adjusted to suit any particular installation

The characteristics of the magnetic amplifier *CR*3, combined with those of *Rec.* 4, are such that for a small difference between the " pattern " and *TG* voltages the output from *Rec.* 4 is proportional to this difference, but for larger differences no further increase in output takes place (fig. 2(B)). The design of the magnetic amplifiers, etc., energised from *Rec.* 4, is such that the maximum output of this rectifier corresponds to a pre-selected maximum torque output from the winder motor.

In order to protect the polarised relay *PR* from excessive current without forfeiting sensitivity, its main coil is shunted by two rectifiers which serve to by-pass current as soon as the normal operating voltage of the relay is substantially exceeded.

Two additional bias windings on this relay enable the operating voltage to be adjusted, and to differ for " driving " and " braking " and to compensate for the idling current of the motor *FM*. These windings may be adjusted to prevent unnecessary changes from driving to braking, and thereby obviate unnecessary wear on the main contactors.

THE EXCITATION SYSTEM.

For the system of excitation, reference should be made to fig. 3. The output from the rectifier *Rec.* 4 feeds the control windings of the magnetic amplifier *CR*2 which are in series with those of the amplifiers *CR*1 (braking) and *CR*4 (driving). The amplifier *CR*2 is associated with the A.C. excitation of the control generator *CG* when driving, or with its D.C. excitation through the rectifier *Rec.* 2 when braking. The magnetic amplifier *CR*1 is associated with the rectifier *Rec.* 1 which supplies the braking D.C. excitation to the winder motor *WM*.

The amplifier *CR*4 controls the A.C. supply for the compensating resistor *RS* from which the excitation for the *LR* coil is derived in accordance with the requirements dictated by the signal current.

THE COMPLETE SYSTEM.

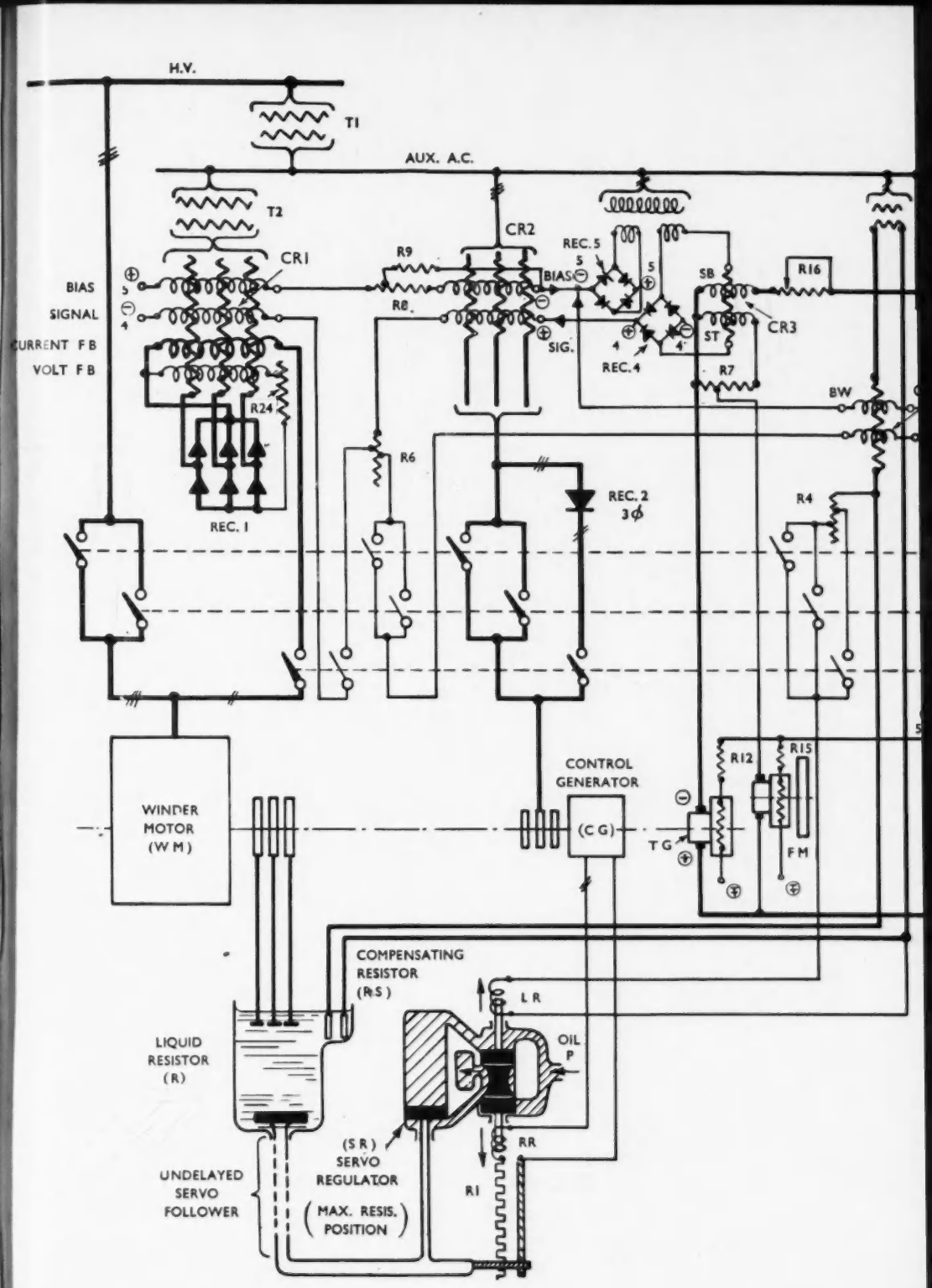
The operation of the scheme (fig. 4) can be understood more easily by considering the sequences following various quick motions of the driver's lever.

(*a*) " *Stop* " *to* " *Half speed Forward* ". Movement of the driver's lever through the gate immediately sets up control circuits for the " forward " direction. Further movement to the half-speed forward position causes the regulator *R*2 to apply 50 per cent of its maximum voltage to the speed-error signalling loop " *TG-CR*3 (*SB*)—*PR* " circuit. The current in the winding *SB* saturates the amplifier *CR*3 which produces its maximum output. At the same time the relay *PR* closes contacts which set up the main contactor circuits for " driving ".

The rectifier *Rec.* 4, associated with *CR*3, also delivers its maximum output to the control windings of the amplifiers *CR*2 and *CR*4. As the control winding opposes the bias winding of *CR*2 this amplifier gives minimum output and hence minimum excitation of the control generator *CG*, which is connected directly to *CR*2 by the " forward " contactor.

On the other hand, as the control winding assists the bias winding *BW* of the amplifier *CR*4, the output from this amplifier produces maximum excitation of the coil *LR* of the hydraulic servo-mechanism. Thus the pull of the coil *LR* is able to overcome that of the coil *RR* and the winder motor *WM* accelerates at the chosen maximum torque as described under the section headed " Rotor Control System ". As the motor gathers speed the tacho-generator voltage rises, and in consequence the current in the speed-balancing winding *SB* falls ; no change takes place, however, in the output from *CR*3 and *Rec.* 4, because this amplifier remains saturated.

Acceleration continues, therefore, at maximum torque until the actual speed approaches that selected, after which the output voltage of the


H.V.
T1
AUX. A.C.
T2
CR1
CR2
R9
REC. 5
BIAS
SB
R16
BIAS
SIGNAL
CURRENT FB
VOLT FB
R8
SIG.
CR3
ST
REC. 4
R7
BW
R24
R6
REC. 2
3φ
R4
REC. 1
WINDER
MOTOR
(W M)
CONTROL
GENERATOR
(C G)
R12
R15
TG
FM
COMPENSATING
RESISTOR
(R S)
LR
LIQUID
RESISTOR
(R)
OIL
P
(S R)
SERVO
REGULATOR
RR
R1
UNDELAYED
SERVO
FOLLOWER
MAX. RESIS.
POSITION

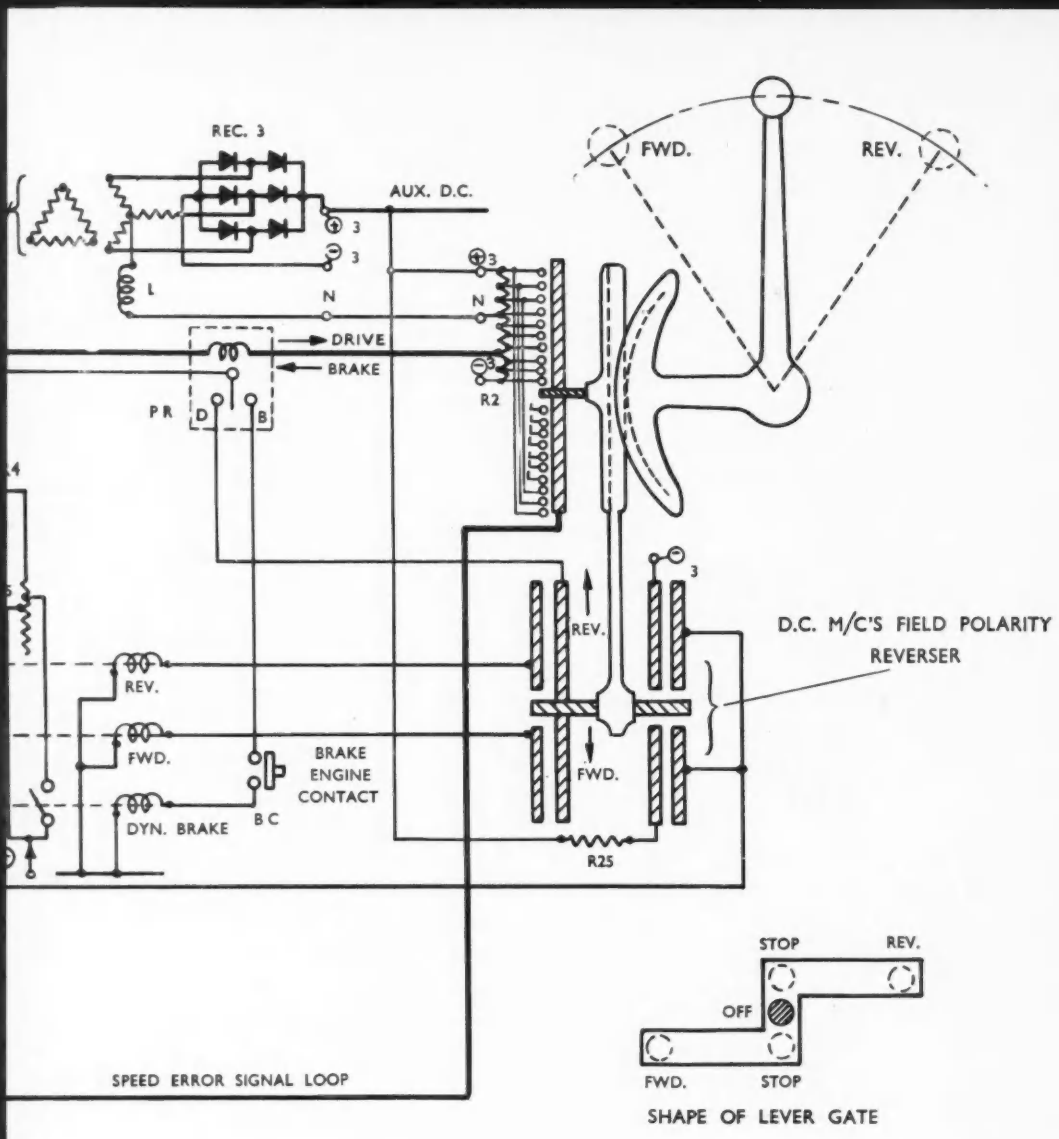


Fig. 4.—Schematic diagram of the speed control system for A.C. winders.

amplifier *CR*4 is rapidly reduced, causing the current in the coil *LR* to fall and the excitation of *CG* to increase, until the torque of the winder motor equals the load torque, so that the speed no longer increases.

As the amplifier *CR*4 is excited by the amplifier *CR*3 via the rectifier *Rec.* 4, the reduction in its output actually occurs a little earlier, because the current taken by *FM* in accelerating with the rising voltage of the tacho-generator *TG*, traverses the stabilising winding *ST* of the amplifier *CR*3. As this current diminishes with the acceleration of *FM*, a stabilising effect is introduced which prevents any tendency for the speed to overshoot the selected value.

As the wind proceeds, the down-going load increases with the length of rope until, in the case of a deep wind, it will ultimately exceed the up-going load. In this event the speed will rise until it exceeds that set by the driver's lever, when the tacho-generator voltage will exceed the pattern voltage, and the current in *SB* and *PR* will be reversed. The reversal of current in *SB* has no effect, because the amplifier *CR*3 is non-directional and gives the same output for a given control current in either direction. The relay *PR*, however, is polarised and changes over its contacts thus causing the main driving contactor to open and the main braking contactor to close.

As a result, the output from the amplifier *CR*3 and the rectifier *Rec.* 4 is transferred to the amplifiers *CR*1 and *CR*2, while *CR*4 receives constant excitation. *CR*1 now supplies an increasing D.C. excitation to the stator of the winder motor *WM* until the braking effort is sufficient to balance the down-going load. A slightly higher speed will be needed to maintain this condition. During this set of circumstances the amplifier *CR*2 supplies D.C. excitation to the control generator *CG* which in turn supplies the coil *RR*.

On entering the retarding zone, the driver's lever is moved back to reduce speed. The tacho-generator voltage then substantially exceeds the "pattern" voltage and full braking excitation (limited by the amplifier characteristics) is applied, so that maximum braking torque is developed.

On reaching bank, the act of setting the mechanical brakes opens the dynamic braking contactor via the contact *BC*.

(*b*) "*Stop*" *to* "*Full speed Forward*". *Regenerative Braking.* Acceleration to full speed will take place at maximum torque, as under (*a*) above. Assuming that the wind is such that regenerative braking is possible, this will begin on a slight rise in speed above synchronism, the resistor *R*2 being set to permit the necessary increase without changing over to dynamic braking.

On entering the retarding zone a backward movement of the driver's lever will cause the polarised relay, *PR*, to change over and initiate dynamic braking.

(*c*) "*Full speed Forward*" *to* "*Full speed Reverse*".—*Reverse-current Braking or Plugging.* The first movement of the driver's lever from "forward" towards "stop" will initiate dynamic braking, since the "pattern" speed will be less than the actual speed. When the lever passes through "stop" towards "reverse", the "pattern" voltage increases once more in the same direction, but as the fields of *TG* and *FM* are reversed the "pattern" and tacho-generator voltages are now additive. The polarised relay *PR*, therefore, maintains the "driving" circuits, and reverse-current braking is applied at maximum torque and under optimum conditions as described above.

An interlock circuit, omitted from the diagram for simplicity, ensures that the resistors *R* and R_1 are at their maximum values before the "reverse" main contactor can close.

A Modern Tanker Using Alternating Current

By C. P. HARRISON, M.I.Mar.E.,
Marine Department.

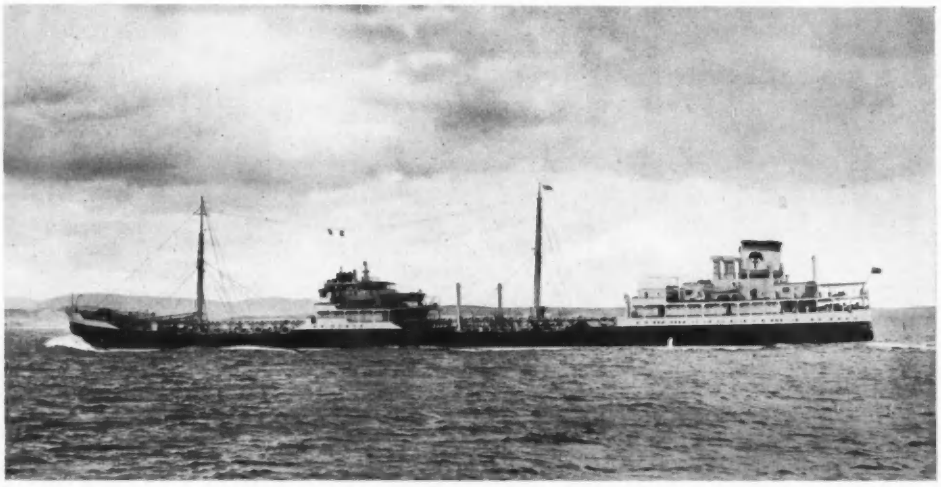


Fig. 1.—The tanker San Florentino.

INTRODUCTION.

THE use of alternating current on ships is still a controversial subject but its adoption has increased considerably in the last two or three years, and building programmes now in hand for the major tanker companies will show an even greater rate of growth in this form of electricity supply. There has been a number of passenger and passenger/cargo ships which have been partially A.C., using it for special purposes such as fluorescent lighting, cabin fans and ventilation and air-conditioning fans, but in most of these cases the generators have been D.C. machines and the current has been converted to A.C. for the power required in this form.

Several all-A.C. passenger ships have been built on the Continent and in America and at least one such ship is now building in Great Britain. It is well known that the Royal Navy is adopting A.C. on a considerable scale but the reasons are largely different from those which apply in the Merchant Service.

The major oil companies, through their tanker-operating associates, have in hand an extended programme of medium and large tankers in which alternating current is used, probably more completely than in any other existing British tonnage. One of the early ships in this programme is the 18,000-ton San Florentino (fig. 1), built by Cammell Laird & Co. Ltd. for the Eagle Oil & Shipping Co. Ltd., and the major part of the electrical equipment has been supplied by The General Electric Co. Ltd.

As the alternators, switchgear, starters and motors were all manufactured by the G.E.C., the design of each was carefully co-related to ensure satisfactory starting of motors with minimum disturbance to the system.

The owners' specification was carefully framed to secure the greatest advantages accruing from the use of alternating current in a tanker, one of the major objects being the reduction of maintenance costs and maintenance time, a matter of prime importance for a vessel having a quick turn-round. After a survey of all the auxiliaries it was decided that the simple squirrel cage motor with single cage rotor could be used throughout. Considerable care was taken to eliminate unnecessary margins of power between the calculated horsepower input to the pumps, or other auxiliaries, and the horsepower output of the motor as specified by the manufacturer of the auxiliaries. This has undoubtedly improved the overall efficiency and power factor of the installation.

The flexibility of A.C. is utilised by stepping down the voltage by means of air-cooled transformers for lighting, appliances and low-voltage inspection lamps. Where direct current is essential, such as for navigation equipment and charging a secondary battery for engine-room emergency lights, it can be easily obtained from transformers and static rectifiers. These arrangements avoid the use of small continuously running motor generators and small batteries and should reduce the possibility of annoying failures and of unnecessary maintenance work.

Though not of vital importance on this tanker, it is of interest to note that the total weight of alternators and motors is only about 70 per cent of the corresponding D.C. machines. This direct comparison is not the whole story because some motors in the San Florentino could not have been D.C. machines and, on the other hand, in a D.C. scheme the number and horsepower of some pumps might be different.

It will be seen that the whole installation takes advantage of the principal claims for alternating current, namely, easy conversion to the most suitable voltage for any given duty, use of the simplest and most reliable motor and direct-switching starter ; high-speed, light-weight and robust alternators ; elimination of radio interference and reduced maintenance. It may be argued that there are certain disadvantages but it is not the purpose of this article to discuss the merits of A.C. versus D.C.

MACHINERY.

The main propulsion machinery in the San Florentino consists of double reduction geared turbines manufactured by the shipbuilders

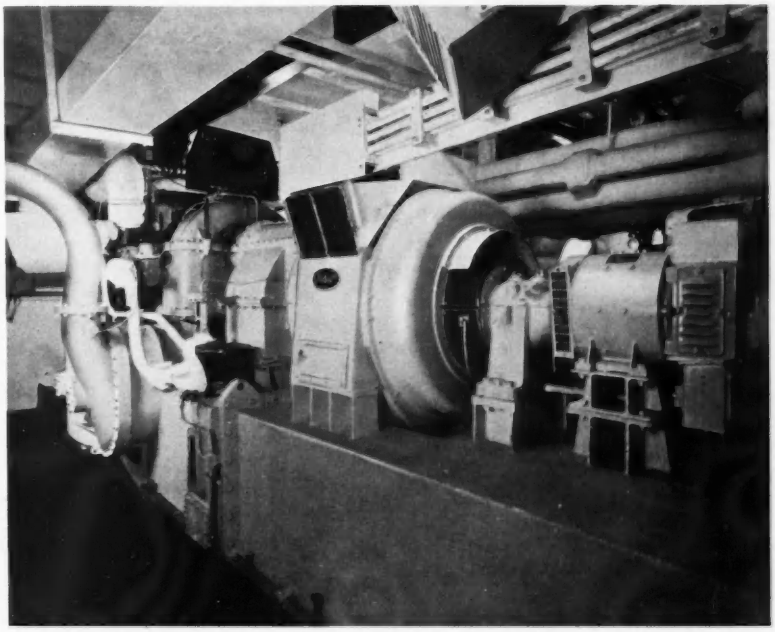


Fig. 2.—One of the 687 kVA, 450 volt, 3-phase, 60 cycle 1,200 r.p.m. alternators with exciters.

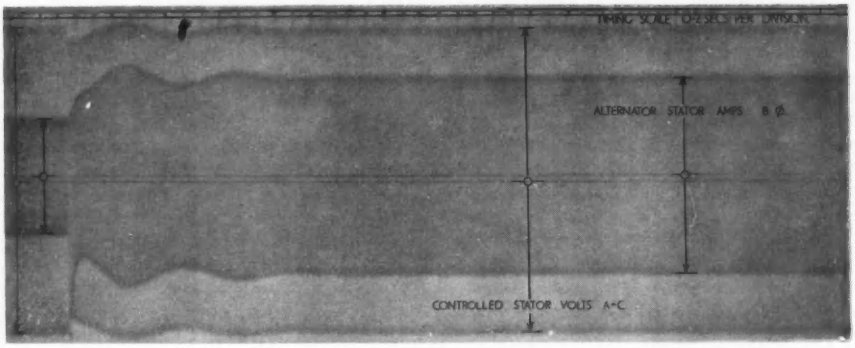


Fig. 3.—Voltage regulation of the 687 kVA alternator with 347 kVA added to the steady load of 450 kVA.

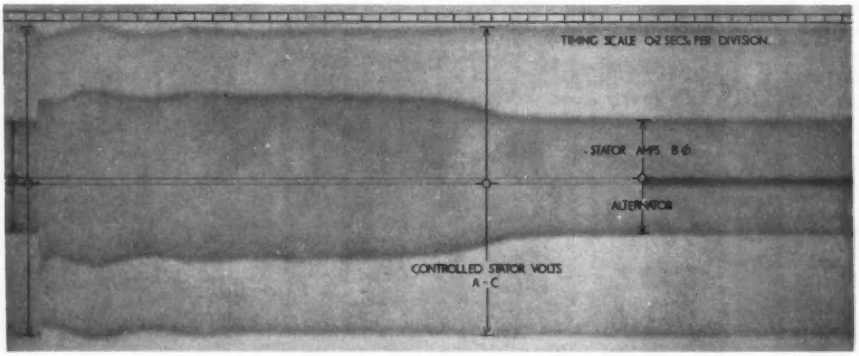


Fig. 4.—Voltage regulation of the 687 kVA alternator, with basic load of 450 kVA, when starting 178 h.p. motor directly on the line.

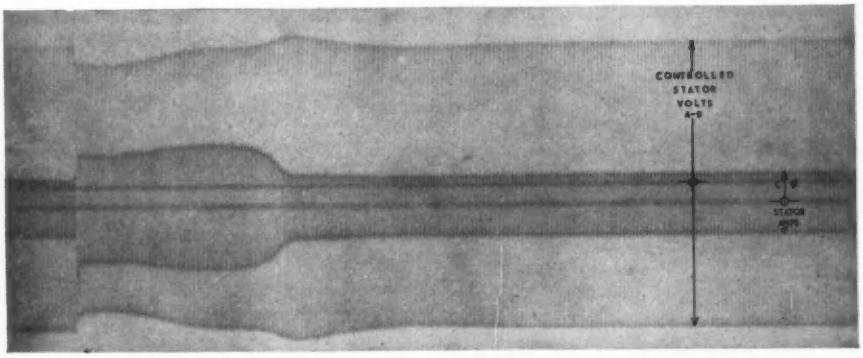


Fig. 5.—Voltage regulation of the 250 kVA alternator on half load when starting the 58·25 h.p. forced draught fan motor directly on the line.

and supplied with steam at 485 p.s.i. superheated to 790 degs. F. and generated by John Thompson " La Mont " oil-fired boilers.

Electric power is obtained from two turbo-alternators each comprising a Brotherhood multi-stage impulse turbine operating under the same steam conditions and driving, through 6,000/1,200 r.p.m. reduction gears, a G.E.C. alternator of 687 kVA, 0·8 p.f., 440 volt, 3-phase, 60 cycles. The alternator is of the salient pole type and has a direct coupled main exciter and 'V' belt-driven pilot exciter. Also, for emergency and port use, there is a G.E.C. 250 kVA, 600 r.p.m. alternator driven by a British Polar six-cylinder diesel engine; this machine also has main and pilot exciters. The pilot exciters generate at a constant voltage of 115 volts, and those on the turbo-alternators also supply current for the speed-control motor on the turbine and for the circuit breaker closing and tripping coils. For this reason they are rated at 4 kW, and are over-compounded so that the peak current of the circuit breaker solenoid does not affect the voltage of the alternator. Each pilot exciter supplies only the circuit breaker for its own set and there are no cross-connections.

The alternators (fig. 2) are drip-proof self-ventilated with terminal boxes on the upper half conveniently disposed for overhead cable connections to the main switchboard. The normal sea load is carried on one large alternator and the port load mainly on the diesel set which has an output sufficient to start from cold ship, including running the forced draught fans, boiler fuel and circulating pumps, as well as other essential auxiliaries. All three alternators can be synchronised and paralleled, and although it will be normal practice to parallel the steam sets to the diesel set before shutting down the latter, it will not normally be necessary to carry out the reverse procedure. For this reason the main alternators have remote-control speeder gear and electrically-operated circuit breakers, whereas, for the diesel set, both speed and circuit breaker are hand-controlled. All alternators have Newton-Derby carbon pile automatic voltage regulators in the field of the main exciter and these, in conjunction with the appropriately designed alternators, aim at minimum voltage dip and rapid voltage recovery on peak loads, especially in respect of the starting currents of the larger motors when switched direct on the line. A typical oscillogram (fig. 3) shows a voltage dip of 8·0 per cent and a recovery time of about 2 seconds when adding a load of 347 kVA at 0·133 p.f., with the alternator already carrying a steady load of 450 kVA at 0·8 p.f. Fig. 4 illustrates the effect of starting the 178 h.p. boiler feed pump direct to line with the alternator already loaded to 450 kVA at p.f. 0·78.

A test on the 250 kVA set was carried out to see the effect of starting on bottom speed the two-speed 58/25 h.p. forced draught fan motor when the alternator was already running at about 50 per cent load (fig. 5).

The automatic voltage regulators are fitted with a power factor compensation transformer to ensure equal distribution of wattless current when the alternators operate in parallel, and a selector switch allows the A.V.R. to be disconnected and the alternator controlled by hand regulators.

MOTORS.

The engine-room motors are all 3-phase squirrel cage induction motors ranging from the 4½ h.p. extraction pump to the 178 h.p. boiler feed pump, and are all single-speed machines except those driving the forced draught fans, transfer pump, fire and bilge pump and engine-room ventilation fans which have double-wound stators for different speed ratios to suit each individual case. All the motors are started by switching direct to line except the 178 h.p. feed pump which has an air-cooled auto-transformer.

After careful consideration it was decided that these few two-speed motors would give all the control necessary for world-wide service and the problem of the main circulating water was solved by having three single-speed pumps (fig. 6), each of 56 h.p., the total volume of water being adjusted by using one or two pumps, the third being a standby. As previously stated, the motors are of the simplest type and have single cage rotors, thus keeping down the size and cost and ensuring maximum reliability. This entails starting currents up to six times full-load current, but the alternators will meet this requirement quite satisfactorily. Most of the motors are enclosed ventilated drip-proof machines with ball and roller bearings and interchangeable terminal boxes and glands, but the forced draught fans, turning and steering motors have plain journal bearings (figs. 7 and 8).

Externally, most of these motors look little different from D.C. machines, but the simplicity of construction is well illustrated by the three photographs of a 178 h.p. feed pump motor (fig. 9).

DISTRIBUTION.

An all-insulated 440 volt, 3-phase system has been adopted on this vessel, employing the spur system of distribution. As will be seen from

TABLE OF AUXILIARY MOTORS.

Duty	No.	H.P.	Speed (r.p.m.)	Duty	No.	H.P.	Speed (r.p.m.)
Accommodation ventilation	2	1/3	1750	Steering gear	2	20	690
,, ,,	2	1	1150	Air compressors	2	8	575
,, ,,	3	5·75	1150	Aux. bilge pump	1	5	1715
Boiler and engine-room ventilator...	2	7·5/4	870/710	Lub. oil pumps	2	23	1150
Boiler and engine-room ventilator...	2	5·5/2·3	1160/870	Transfer pump	1	12½/13	690/575
Turning gear	1	5	850	General service pump ...	1	30	1750
Fresh water extraction pumps	2	4½	1710	Fire and bilge pump ...	1	30/10	1750/1150
Evaporator drain pumps ...	2	4½	1150	Main feed pump	1	178	3,500
Main circulating pumps ...	3	56	865	Cargo condenser extraction pump	1	10	1740
Aux. circulating pumps ...	2	31	1160	Main extraction pumps ...	2	18½	1740
Evaporator booster pump...	1	7	1150	Standby boiler circ. pump...	1	26	1150
Heater drain pump ...	1	12	1750	Boiler circ. pumps... ...	2	15	
Forced draught fans ...	2	58/25	1160/870	Turbo-generator extraction pump	2	5	1730

Fig. 6.—56 h.p. 440 volt, 865 r.p.m. main circulating pump and motors driving other auxiliaries.

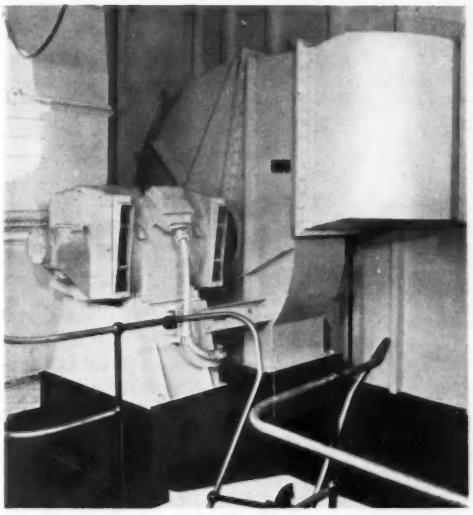


Fig. 7.—58/25 h.p., 1,160/870 r.p.m. forced draught fan motor.

fig. 12, 440 volt feeders are carried to the two group starters, and the aft and midship's sub-switchboards. From the latter, and similarly from the main board, there are supplies to two groups of air-cooled transformers which reduce the voltage to 115 for all lighting and small power appliances. These low-voltage circuits are substantially balanced and the transformers each consist of four single-phase units, one unit acting as a standby and so arranged that it can easily be connected in place of any one of the three in service in the unlikely event of a fault. Thus, one transformer supplies all aft accommodation, deck and machinery spaces, and the other supplies midship accommodation, bridge and fo'c'sle.

SWITCHGEAR.

The introduction of 440 volt alternating current on ships has made essential the use of fully enclosed and protected switchgear. The Company has developed a modern style cubicle with air-break switchgear for controlling power-station auxiliaries and for industrial installations and this construction was very readily adaptable to marine duties. The cubicles are suitable for accommodating manually- or electrically-operated circuit breakers, fused switches, contactors, isolators and a full range of instruments, and the same construction can therefore be applied to the main switchboards, group starters, sub-switchboards and individual starters (fig. 10). The construction is such that no supporting framework is necessary and the unit parts are so designed that cubicles up to 6 ft. 6 in. high can be assembled in standard widths from 1 ft. 6 in. to 3 ft. 6 in. and used as individual cubicles or joined together to form one switchboard. This simplicity is obtained by forming the top and

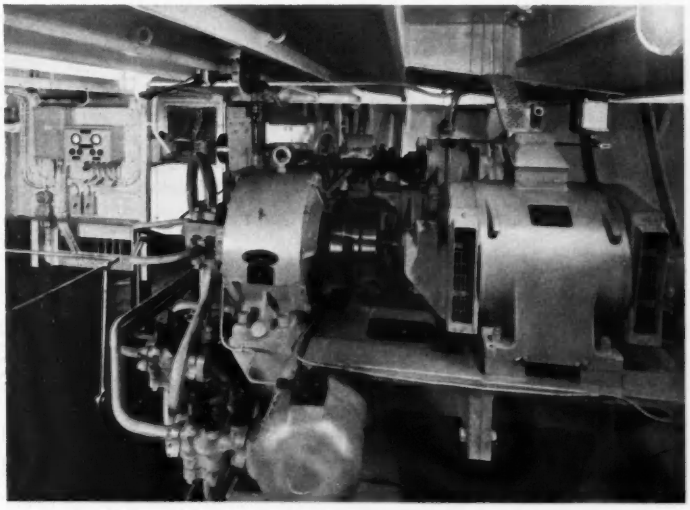
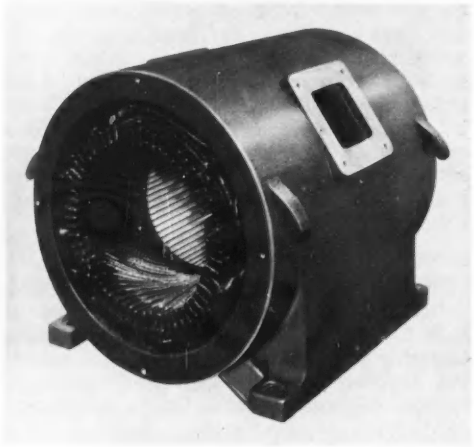


Fig. 8.—20 h.p., 690 r.p.m. steering gear motors and local control unit.



side plates from sheet steel with edges bent in 'U' form and the inner edges bolted together to form a rigid structure. Both back and front have hinged doors, all hinges and hinge fixings being invisible and so arranged that the spacing between doors is only $\frac{1}{4}$ in. The rear doors can also be completely removed.

The switchgear is mounted on insulating panels, which in turn are carried on an internal skeleton frame and all parts which might normally require attention, such as contacts, trip coils, overload settings and fuses, are accessible from the front, but interlocks ensure that these parts must be isolated before the front door can be opened. Busbars, current transformers and so forth are situated behind the panel but are accessible through the rear doors which are fastened by special keys.

These cubicles are finished in light grey

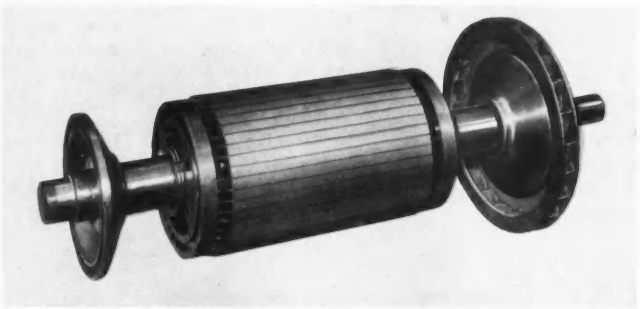
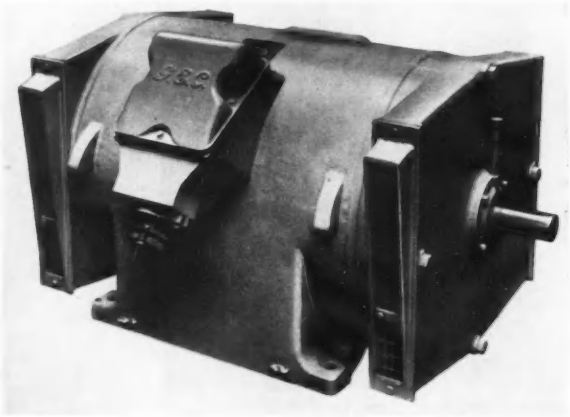


Fig. 9(*a*) (*above*).—Stator of 178 h.p. high-speed boiler feed pump motor.

(*b*) (*right*).—Rotor of the boiler feed pump motor.

(*c*) (*below*).—Boiler feed pump motor.



stoved enamel and are free from all nuts or bolt heads. Cable entry is either from the top or bottom and in the case of single cubicles, such as are used for starters, may be from the side.

The main switchboard is 14 ft. long by 6 ft. 6 in. high by 3 ft. 6 in. deep, and because of the totally enclosed construction no additional gates or screens are necessary. The 3 ft. space required for access to the rear doors is normally a safe clear passage way. The equipment of this board is simple, consisting of three alternator circuit breakers, a synchronising panel, four feeder circuit breakers

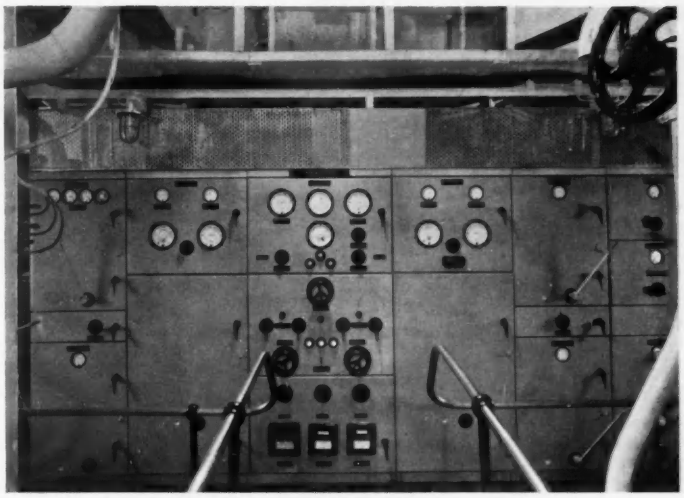


Fig. 10.—Cubicle type main A.C. 440 volt switchboard.

and four fused switch feeders. A line diagram is shown in fig. 15.

All switchgear has a breaking capacity in excess of the 12 MVA necessary for this particular installation, and although the circuit breakers could all have been electrically-operated it was decided to apply this feature only to the two main alternator breakers where it is necessary to simplify synchronising. The field regulators, A.V.R. trimmers, turbine speeder gear switches and circuit breaker control switches are all grouped on the synchronising panel with appropriate instruments and reverse power relays. The selector switch connects the synchronising instruments to the incoming alternator and embodies an interlock with the circuit breakers

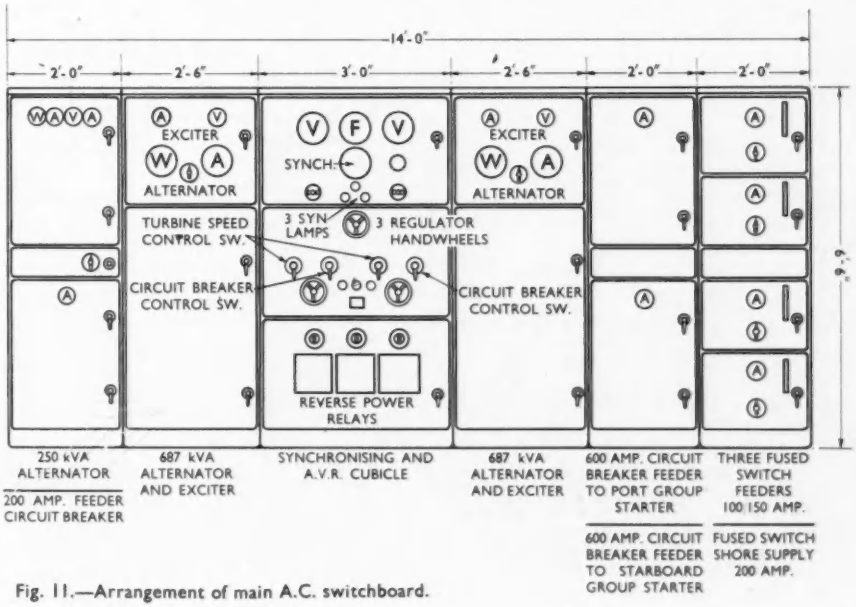


Fig. 11.—Arrangement of main A.C. switchboard.

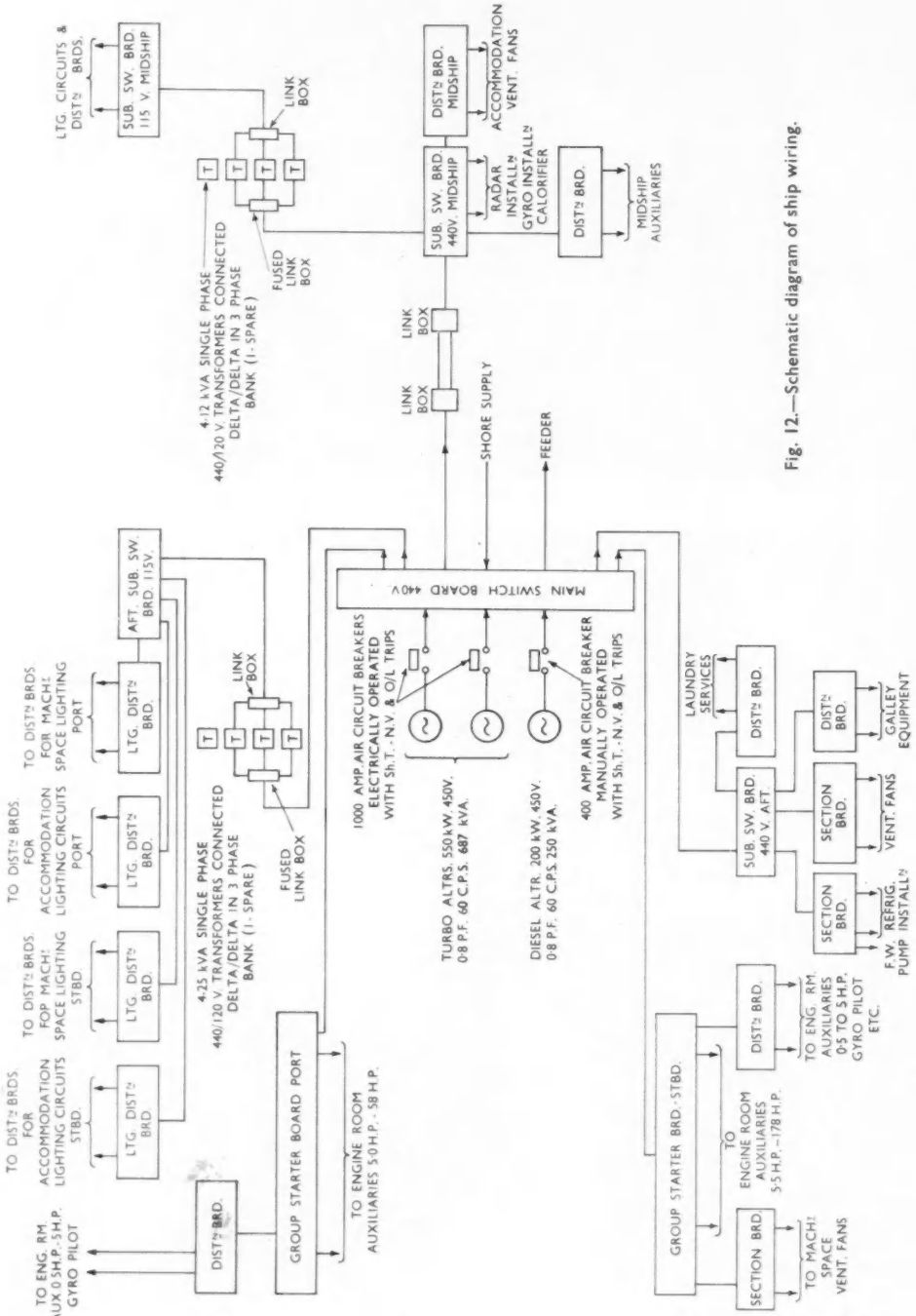

LTG. CIRCUITS & DIST.ⁿ BRDS.
SUB. SW. BRD. 115 V. MIDSHIP
LINK BOX
T
4·12 kVA. SINGLE PHASE 440/120 V. TRANSFORMERS CONNECTED DELTA/DELTA IN 3 PHASE BANK (1 - SPARE)
FUSED LINK BOX
DIST.ⁿ BRD. MIDSHIP
ACCOMMODATION VENT. FANS
SUB. SW. BRD. 440V. MIDSHIP
RADAR INSTALLⁿ GYRO INSTALLⁿ CALORIFIER
DIST.ⁿ BRD.
MIDSHIP AUXILIARIES
LINK BOX
LINK BOX
SHORE SUPPLY
FEEDER
MAIN SWITCH BOARD 440V
1000 AMP. AIR CIRCUIT BREAKERS ELECTRICALLY OPERATED WITH Sh.T. - N.V. & O/L TRIPS
TURBO ALTRS. 550 kW. 450V. 0·8 P.F. 60 C.P.S. 687 kVA.
DIESEL ALTR. 200 kW. 450 V. 0·8 P.F. 60 C.P.S. 250 kVA.
400 AMP. AIR CIRCUIT BREAKER MANUALLY OPERATED WITH Sh.T. - N.V. & O/L TRIPS
LAUNDRY SERVICES
DIST.ⁿ BRD.
SUB. SW. BRD. 440 V. AFT.
DIST.ⁿ BRD.
SECTION BRD.
SECTION BRD.
VENT. FANS
GALLEY EQUIPMENT
F.W. REFRIG. PUMP INSTALLⁿ
TO ENG. RM AUXILIARIES 0·5 TO 5 H.P. GYRO PILOT ETC.
TO ENGINE ROOM AUXILIARIES 55 H.P. - 178 H.P.
GROUP STARTER BRD. - STBD.
DIST.ⁿ BRD.
SECTION BRD.
TO MACH.ᵗ SPACE VENT. FANS
TO ENG. RM AUX. 0·5 H.P. - 5 H.P. GYRO PILOT
TO DIST.ⁿ BRDS. FOR ACCOMMODATION LIGHTING CIRCUITS STBD.
TO DIST.ⁿ BRDS. FOR MACH.ᵗ SPACE LIGHTING STBD.
TO DIST.ⁿ BRDS. FOR ACCOMMODATION LIGHTING CIRCUITS PORT
TO DIST.ⁿ BRDS. FOR MACH.ᵗ SPACE LIGHTING PORT
LTG. DIST.ⁿ BRD.
LTG. DIST.ⁿ BRD.
LTG. DIST.ⁿ BRD.
LTG. DIST.ⁿ BRD.
AFT. SUB. SW. BRD. 115V.
4·25 kVA. SINGLE PHASE 440/120 V. TRANSFORMERS CONNECTED DELTA/DELTA IN 3 PHASE BANK (1 - SPARE)
LINK BOX
FUSED LINK BOX
GROUP STARTER BOARD PORT
TO ENGINE ROOM AUXILIARIES 50 H.P. - 58 H.P.
DIST.ⁿ BRD.

Fig. 12.—Schematic diagram of ship wiring.

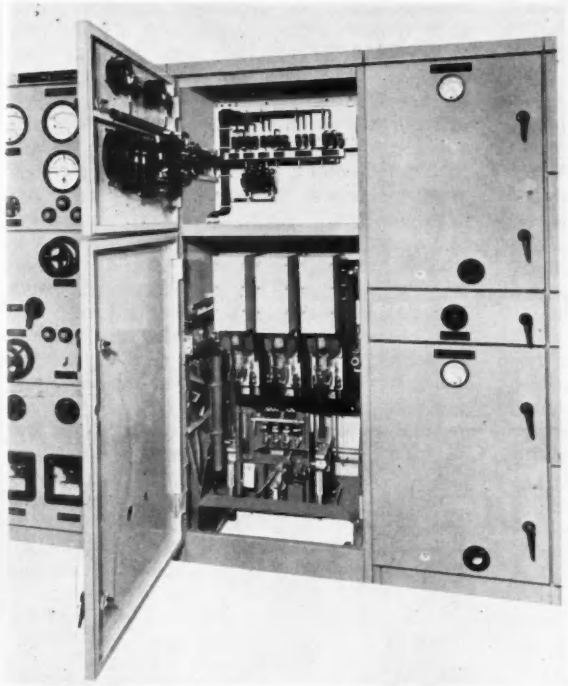


Fig. 13.—Main switchboard with door open to show 687 kVA alternator circuit breaker.

breakers are of the withdrawable type ; those for the 687 kVA alternators occupy a full height of the cubicle and are withdrawn on rollers at deck level. For the smaller size circuit breaker the switchboard is divided horizontally into two cubicles, but each circuit breaker is withdrawn in a similar manner and is light enough to be handled for complete removal. The feature of all these circuit breakers is that they are connected to the busbars by wedge and finger-type contacts so that, when switched off, they can be withdrawn to the isolated position by means of a screw and nut racking mechanism without opening the cubicle door. The door may then be opened and the circuit breaker can still be operated in its normal upright position for observation and adjustments with complete safety (fig.13). In both connected and isolated positions the circuit breaker is unaffected by ship movement, and from the isolated position, by releasing a lock, it may be removed completely from its cubicle.

The circuit breaker itself consists of a fabricated steel frame with an

so that only the correct one can be closed. All circuit breakers have triple pole overload coils with time-lag dashpots filled with silicone fluid ; the alternator breakers have, in addition, a no-volt release and a shunt trip. The reverse power relays have been specially developed to trip at 3 per cent full load, a necessary precaution for turbo-alternators which require very little power to continue motoring from the busbars, which might be a serious matter if the turbine stop valve trips due to failure of the lubricating oil or the vacuum. The circuit

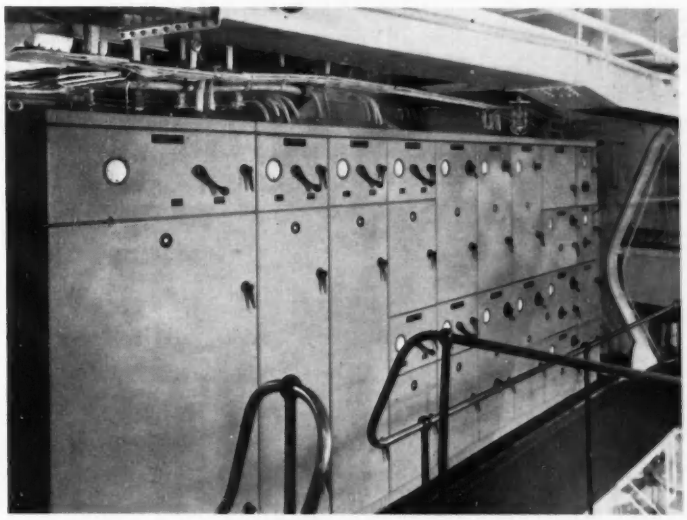


Fig. 14.—Starboard group starter board.

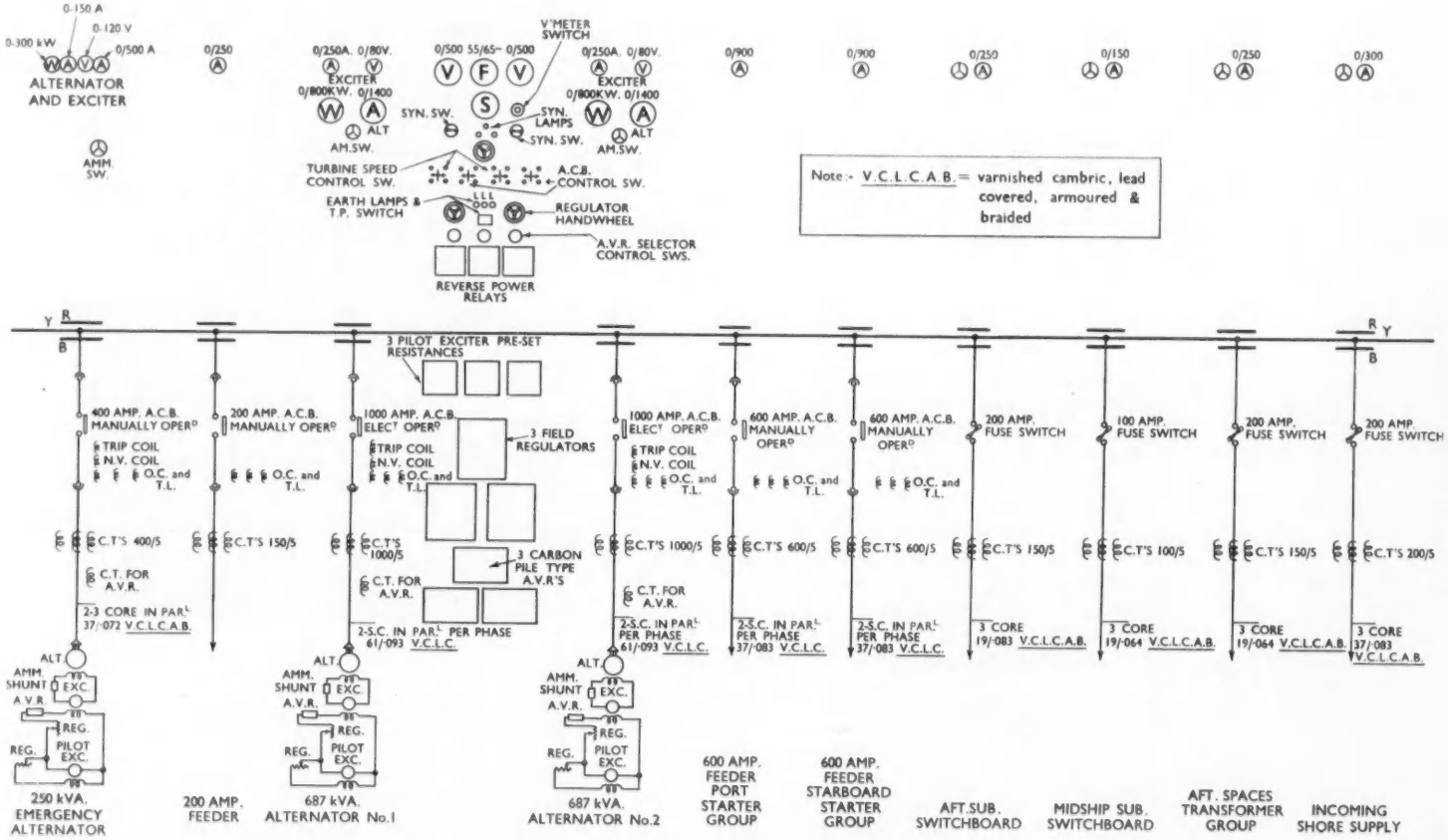


Fig. 15.—Single line diagram of main A.C. switchboard.

insulating panel carrying the fixed contact assemblies. The silvered butt type moving main contacts and the moving arc contacts are mounted on hinged arms with insulating members. The contacts are enclosed in box-type arc chutes which are easily removable. The operating handle is attached to a shaft which projects through a hole in the door and is fitted with a pointer which not only shows whether the breaker is in the "on" or "off" position but also whether it is in the service or isolated position. The smaller feeders and the shore line connection are controlled by "on load" quick make-and-break fused switches operated by removable external handles and interlocked with the doors which cannot be opened when the switch is closed or the switch closed when the door is opened. The high rupturing capacity fuses are held in captive quick-release terminal screws.

All circuits have ammeters, including an ammeter switch on the alternators and on the feeders to transformers which may have an unbalanced load.

GROUP STARTERS.

The port and starboard group starters (fig. 14) which, as already stated, are constructed of cubicles similar to the main switchboard, cover all engine-room auxiliaries except a number below 5 h.p. which have small separate starters. This method of grouping starters is similar to that used quite widely on D.C. ships, including the plural starter system, and saves cable and circuit breakers or switches on the main switchboard ; it is also of assistance in obtaining reasonable discrimination in the isolation of faulty apparatus. It should be noted that since one alternator supplies full sea load, no preference tripping is necessary on the main switchboard or starters. Each starter is in its own cubicle with the isolating switch fully interlocked with the door, and all working parts are accessible within this door. Most starters have a triple pole D.T.L. contactor, three overload relays with silicone dashpot time-lags and H.R.C. back-up fuses ; all contactor-operating coils and pilot lights operate from a 115 volt supply obtained from a transformer in each starter. The two-speed motors have two triple pole contactors and two sets of overload coils. There are several special cases, such as the two-speed forced draught fans of 25/58 h.p., which have a high inertia load and which will start up only on the bottom speed irrespective of which push button is pressed, and have a timing relay adjustable to allow time for the machines to run up to this speed before the starter changes over to the top-speed connection (figs. 16 and 18). Smaller two-speed motors can be started direct on either speed, but in all cases there is a mechanical interlock between the two sets of contactors. The 178 h.p. feed pump motor has an auto-transformer starter which has a mechanical time delay controlling the changeover from the

Fig. 16.—Front view of port group starter board : a two-speed starter on the right and, next to it, two single-speed starters.

starting tapping to the line connection. On this particular starter the overload relays are short-circuited during the starting period but other starters have double dashpots on the overload relays to cover the period of heavy starting current, although at other times they would give normal overload protection. The steering gear starters are embodied in these group boards and, in accordance with normal practice, have two sets of line contactors. The engine turning gear has a normal squirrel cage motor and the starter, apart from forward and reverse contactors, has a stator resistance in order to reduce the shock when the gear takes up its drive. This resistance is short-circuited after a short time delay.

The 'start' and 'stop' push buttons for the majority of motors are mounted in small boxes with pilot lamps adjacent to the motor, or at appropriate control points such as the boiler-control platform. Many of them have additional emergency 'stop' push buttons at upper deck level (fig. 18).

The H.R.C. backup fuses have been carefully selected in each case in relation to the starting currents and starting times and yet give short-circuit protection to the combined cable and motor circuit.

The smaller individual starters are constructed on exactly similar lines to the group starter cubicles as clearly illustrated in the exterior and interior views in figs. 19 and 20.

CABLE.

The connections from the alternators to the switchboard are 61/·083 single core, varnished cambric, lead-covered and braided 660 volt grade cable, two in parallel per phase and carried in insulators protected where necessary by metal screens. Cable glands on the alternators and switchboard are in bakelised fabric gland plates and the cable sheaths are earthed at the mid-point to avoid circulating currents in the sheath. For the principal feeders and motors varnished cambric, lead-covered, armoured and braided cable is used. Small wiring is by means of V.R., L.C., A. and B. cable and all are run on cable trays in an orthodox manner. The 115 volt circuits are wired with 250 volt grade V.R., L.C. and B. in twin and multi-core forms.

GALLEY.

The 440 volt, 3-phase supply is used in the main galley where the equipment includes a two-oven range, single deck baking oven, prov-

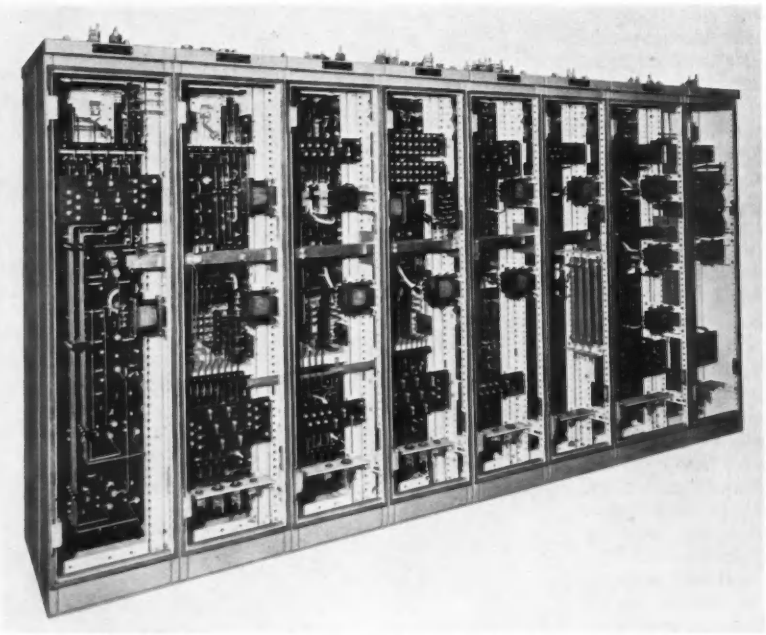


Fig. 17.—Rear view of port group starter board with doors removed.

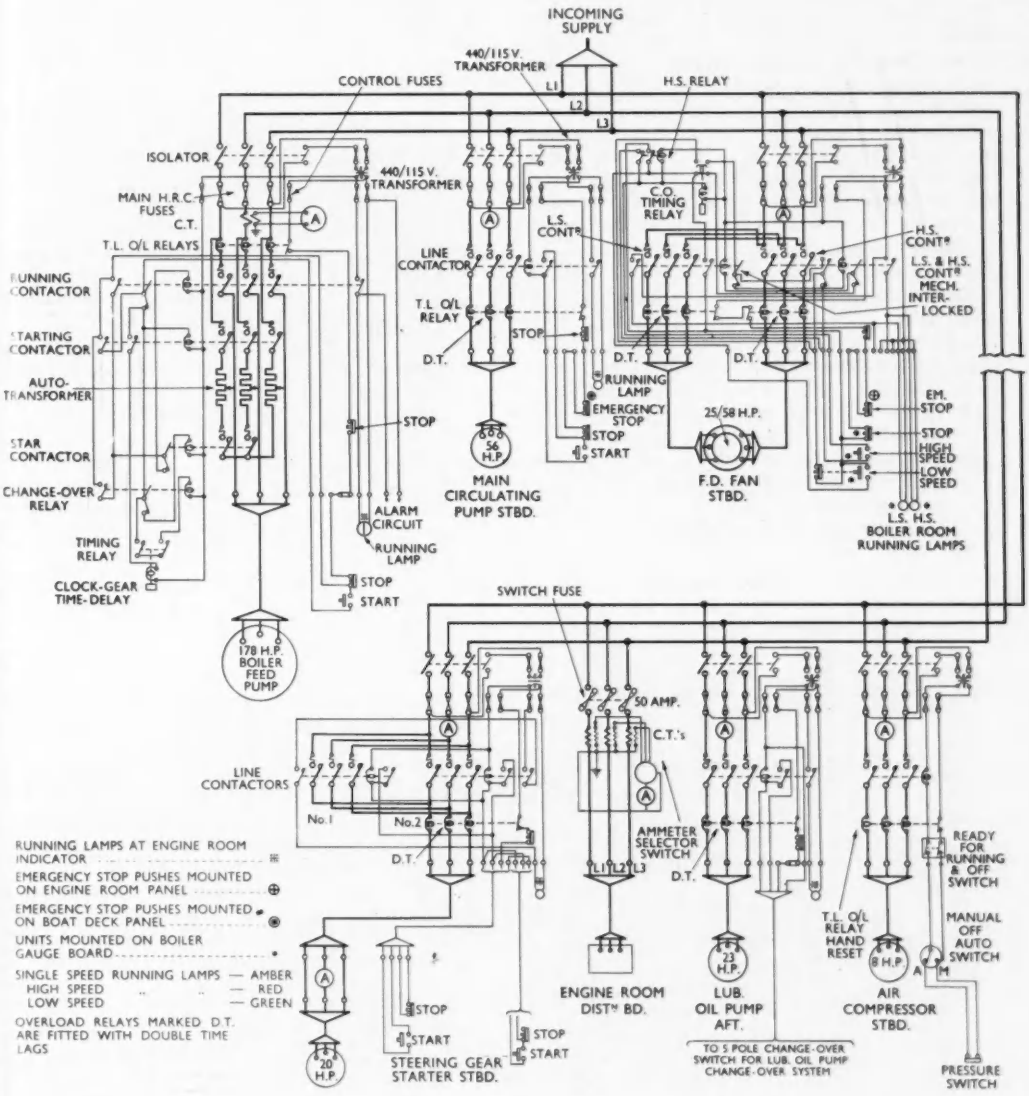


Fig. 18.—Schematic diagram of connections for part of the starboard group starter board.

ing cupboard, steaming oven, griller and water boiler.

Cooking equipment for a 440 volt all-insulated system has already been supplied to other merchant ships and to the Royal Navy, so that the general construction is of the Company's normal type. Particular thought was given to the design of roasting oven elements, especially as this contract was received at a time of extreme shortage of nickel alloy which is normally used for sheathed-wire elements. For this and other reasons an oven element was designed using standard type 220 volt sheathed-wire heaters, connected two in series and carried in secondary insulation inside a perforated metal screen. The outer sheath of the element cannot be touched until the complete assembly is withdrawn from the oven and this is no more difficult than removing the usual sheathed wire element alone. This construction has the following advantages:

1. Standard type 220 volt elements are used.
2. Higher efficiency due to thinner refractory insulant.
3. Reduced electrical stresses on sheathed-wire heater, especially at point of entry of lead-in wires, because of secondary insulation and divided sheath.
4. Greater mechanical strength due to bench assembly of the complete element.

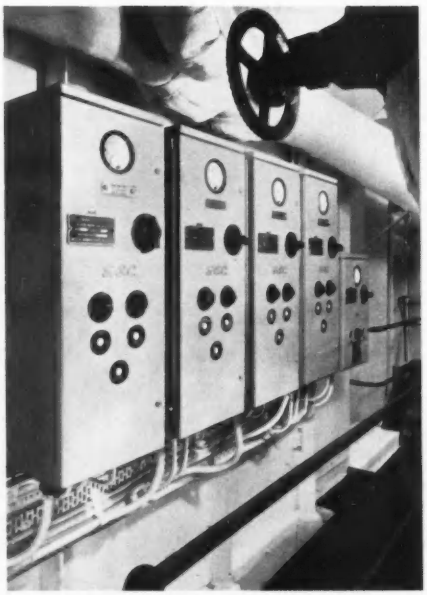


Fig. 19.—Two-speed DTL starters for boiler room and engine-room fans, and single-speed DTL starter for accommodation ventilation fans.

The boiling-plates are the normal 16 in. by 12 in. size, 440 volts with three-heat control. "Austinlite" 440 volt switches, H.R.C. fuses and indicating lamps are housed in a separate control panel with the isolating switch interlocked with the cover.

Fig. 20.—Single-speed DTL starter for 5 h.p. motor.

Normal tubular elements are fitted in the baking ovens. The element wire on formers is withdrawable from the sealed tube through inspection covers on the oven front.

Radiant coil heaters are most efficient for grillers and toasters; fireclay formers embrace the coils and there is also a heat-resisting non-conducting rod through the coil so that there is no risk of a sagging or broken element.

The range has a total loading of 24 kW, and other items bring the total connected load to 46 kW. Hotcupboards, small boilers and coffee percolators in pantries are operated on 115 volts.

MISCELLANEOUS APPARATUS.

Apart from the major problems of generators and other electrical machinery, considerable care has been given to various electrical accessories which are particularly suitable for tankers. In the 15-amp. water-tight socket and plug used for portable tools and handlamps, the switch is fully interlocked so that the plug cannot be inserted or withdrawn except with the switch in the 'off' position and the switch cannot be closed when the plug is out. Plug pins are shrouded to avoid mechanical damage and the

plug top can have 5-amp. fuses inserted in place of solid links when used with hand lamps or low-current appliances. Silent D.P. microgap switches are used in all accommodation, as also are 12 in. induction pattern, three-speed bracket fans.

TRIALS.

The San Florentino left the Mersey on March 27th and ran speed trials in the Clyde before returning to Birkenhead. During these trials, and the dock trials which preceded them, no difficulties were experienced with the synchronising of alternators or the starting of motors. Ammeter readings on various motors showed the full load currents to be remarkably close to the estimated values, which justified the special care taken to avoid unnecessary margins. A number of spot readings indicated a power factor varying between 0·8 and 0·86 lagging.

CONCLUSION.

The San Florentino sailed on her maiden voyage to the Persian Gulf on March 31st, 1953 and at the time of going to press is homeward bound on her second voyage.

The excellent service given by the electrical installation in this ship and others of her class should dispel any fears that alternating current equipment is complicated and that synchronising and other operations are difficult, or that the higher voltage is liable to cause more faults or to prove dangerous. There is every confidence that the simplicity of operation will be maintained and that maintenance costs will be held to a very low figure.

A sister ship, San Fernando, will shortly be entering service, and other ships of the same class in various shipyards for The Anglo-Saxon Petroleum Co., Ltd., and the Eagle Oil & Shipping Co., Ltd., will have similar electrical equipment except for minor changes in sizes of motors by reason of the use of different types of boilers.

In later ships the alternators will be driven by G.E.C. turbines. The experience gained in equipping these ships will be of great value when preparing designs for other classes of tonnage, including passenger ships, which will without doubt adopt alternating current on an increasing scale.

ACKNOWLEDGMENTS.

Thanks are due to Cammel Laird & Co. Ltd., who were responsible for the installation of all the electrical equipment in the San Florentino and for supplying the information included in this article.

Acknowledgment is also made to the Eagle Oil & Shipping Co., Ltd., for permission to publish the foregoing description.

Fig. 21.—Electric pantry with hot cupboard and water boilers.

A Note on the Relative Discomfort Glare from Mercury, Sodium and Tungsten Light Sources

By H. M. FERGUSON, A.M.I.E.E., J. REEVES and W. R. STEVENS, B.Sc., M.I.E.E., F.I.E.S.
G.E.C. Research Laboratories.

MANY recent street lighting installations have used sodium lamps, so that, taking into account the numerous existing mercury installations, the general public and lighting engineers have had every opportunity of comparing the two systems. The result appears to be a significant preference for sodium by many people.

It is difficult to assess the reasons for this preference. There are many variables in street lighting installations, e.g. road surface characteristics, mounting height and spacing of lanterns, light distribution, effect of adjacent houses and trees, age of installations, which produce large variations in performance so that it is nearly impossible to make valid comparisons between different light sources. The comparison is, therefore, built up in an observer's mind by impressions gained from seeing a large number of installations.

It is often difficult also to discover why an individual prefers one form of street lighting to another. Sometimes better visibility is claimed; 'more sparkle', 'better contrast' and 'softer lighting' are terms which have been used. The most commonly held opinion, however, is that sodium street lighting is less 'glaring' or 'dazzling' than mercury.

Several formal experiments have been made but have failed to support these opinions. Dr. J. W. T. Walsh speaking in a discussion at a conference of the Association of Public Lighting Engineers,* stated that he did not know of any scientific evidence that one colour was better than any other as regards street lighting. When experiments were carried out at the National Physical Laboratory to reproduce similar conditions under different coloured lighting they could not detect any certain differences as to the ease with which an object could be seen on the road, whether the colour was blue, green, yellow, or any other colour. Similar statements have been made by others.*

Nevertheless, it was thought worth while making a formal investigation of the relative discomfort glare from bright mercury and sodium sources. These studies have now been in progress for nearly three years and have yielded interesting and unexpected results. Since it is likely to be some time before the work is completed it is thought to be of value to give an interim summary of the more important results obtained so far.

The first experiments were designed to establish whether the brightness distribution over the face of a practical lantern had a significant effect on glare. It was found that this was not so, for it appeared not to matter whether the lantern presented a uniform 'flash' of low brightness or a mosaic of high lights which could not be resolved at normal viewing distances. If the average brightnesses and the areas were equal the two lanterns were deemed equally glaring.

In the main series of experiments, mercury, sodium and tungsten sources have been observed under carefully controlled conditions which may not, however, be directly related to conditions obtaining in the street. The basis of the experiment was to present to a number of observers a pair of different sources, for example, mercury and sodium, comparable in size and brightness with those of street lighting lanterns. Each source was uniformly bright over its surface. The size and viewing distance and, therefore, the angular subtense of each source was the same and they were seen in close proximity side by side. The dimensions of the sources and their separation are shown in fig. 1 and the viewing distance was 80 ft.

The brightness of the sources, and therefore the intensity, was varied and for each condition

* *Public Lighting*, *15*, 192 (1950).

* W. R. STEVENS—"Principles of Lighting" (Constable, London, 1951).

the observers were asked to state whether one source was more glaring than the other or whether there was nothing to choose between them. After a period of dark adaptation, opinions were obtained immediately on viewing the sources and again after having looked at them for 1 minute. In this type of experiment the observer is asked a simple question to which only one of three answers is allowed; ' yes ', ' no ', ' don't know '. There was no question of trying to determine how much more glaring one source was than the other.

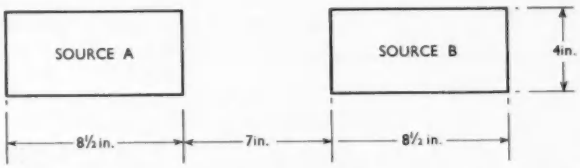


Fig. 1.—Dimensions and arrangement of sources. Viewing distance: 80 ft.

A simple system of marking was adopted so that the judgment of each observer could be recorded numerically. Each observer was allocated one mark for each test. If he decided that source A was more glaring than source B his mark was placed against A and vice versa: if he decided that there was nothing to choose between the sources half a mark was placed against each. In this way the observer who has no preference is not ignored but his judgment is weighed in with those who have. The number of marks placed against one source expressed as a percentage of the total is used throughout this note for the ordinate of the graphs. This ordinate is described for convenience as the percentage of observers who judge one source to be more glaring than the other,* though the number of observers who have no preference may be important in determining the ' uncertainty factor ' of the tests. The number of observers used for each test was not less than twelve.

The experiment was repeated with backgrounds which substantially filled the whole field of view, of different luminance and colour; and also with tungsten/mercury, and tungsten/sodium comparisons.

COMPARISON OF MERCURY AND SODIUM SOURCES.

The sodium source was run at a constant brightness of 44 cd/in^2 producing an intensity, *Is*, of 1,500 *cd*. The mercury source, which is intrinsically brighter, was varied by placing neutral filters in front of it, in order to obtain suitable values of intensity, *Im*. In this way a suitable range of values for the ratio Im/Is was obtained and each observer in turn was asked to give his opinion for a number of definite values.

The first test was made with $Im=Is$, and with a dark background. The results showed that nearly 100 per cent. of the observers judged the mercury source to be more glaring than the sodium immediately on looking at them and after one minute the percentage fell slightly to about 90 per cent.

Results for a number of tests are shown in the graph (fig. 2) which indicates that the ratio Im/Is must be reduced to about one-third before the opinion of the observers initially is equally divided (curve 1). After viewing for one minute the results are similar (curve 2).

COMPARISON OF TUNGSTEN WITH MERCURY AND SODIUM SOURCES.

Similar tests to those described above have also been made with tungsten and mercury sources and with tungsten and sodium sources.

The comparison of tungsten and mercury sources against a dark background showed that, when the intensities were equal, some 60 per cent of observers judged the mercury source to be more glaring than the tungsten after one minute. The ratio of Im/It had to be reduced to about 0·8 before the opinion of observers was equally divided. (The small difference might be explained by experimental error.)

Similarly, a comparison of tungsten and sodium showed that about 85 per cent of the observers judged the tungsten to be more glaring than the sodium when their intensities were equal and the ratio It/Is had to be reduced to about one half for equality of judgment.

The interesting result from this test is that the tungsten source falls in between the mercury and sodium sources: for equal intensities the mercury is more glaring than the tungsten and the tungsten more glaring than the sodium. The inevitable inference that a mercury source will be more glaring than a sodium source is borne out in the first experiment.

EFFECT OF SURROUND BRIGHTNESS.

All the tests described so far were made with a dark surround and a further series of tests was made to establish the effect, if any, of surrounds of various brightness and colours.

Fig. 3 shows the effect of background bright-

* This percentage is sometimes referred to as ' glare factor ' in these notes. It is not a measure of the relative glare of the two sources.

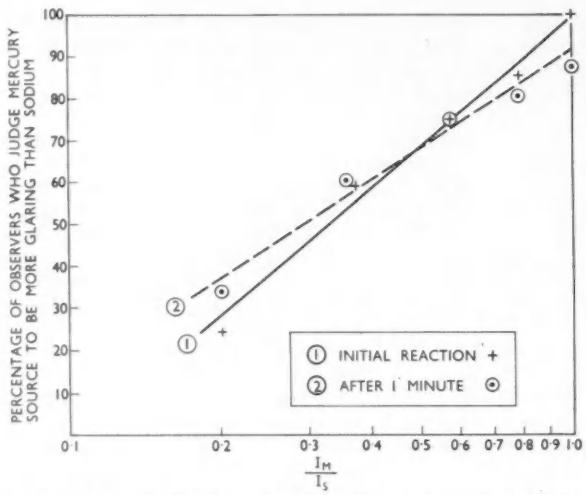


Fig. 2.—' Glare factor ' for mercury/sodium comparison with dark background.

$$\frac{Im}{Is} = \frac{\text{Intensity from mercury source}}{\text{Intensity from sodium source}}$$

ness (mercury and sodium light) on the judgment of glare from mercury and sodium sources after one minute's viewing. Fig. 4 shows results obtained in a comparison of tungsten and sodium sources with various values of background brightness (tungsten light) and for various values of *It*/*Is*.

The curves show that for any particular intensity ratio of the sources being compared the ' glare factor ' between the two sources tends to become smaller as the background brightness is increased up to a value of about 1 ft. lambert. Beyond this value the reduction in ' glare factor ' with increasing background brightness becomes insignificant and even at a level of 10 ft. lamberts the ' glare factor ' is still appreciably above 50 per cent.

Similar results are obtained whichever source is used for the background. The values are slightly different but the general inference remains that above a value in the region of 1 ft. lambert, the level of background brightness has no significant effect on the ' glare factor '.

INTERPRETATION.

These results are quite unexpected and no simple explanation has been found. The intensity measurements were made by measuring illumination at the observer's eye with a visual photometer calibrated on the standard photopic scale. It would be expected that two sources producing equal illumination on the observer's eye (operating under photopic conditions) would appear equally bright and differ only in colour. Is it possible that the relative luminous efficiency curve used as a basis for photometry in photopic conditions does not hold at the high luminance values used in these experiments ?

The following experiment was designed to give further information on this. The mercury and sodium sources were set up side by side, as shown in fig. 1, against a dark background. They were first adjusted to give equal measured luminances of 55 *cd*/*in*^{2}; this is the condition in which observers would be expected to find the two sources equally glaring, but in which, in fact, the majority found mercury more glaring.

The two sources were now reduced in luminance equally and in steps of about 10 to 1. To ensure that the spectral distribution of the sources was not altered by this reduction, the lamps were operated on direct current and a sector disc interposed between them and the observer. It was not possible to achieve all the required reduction by this means, however, so

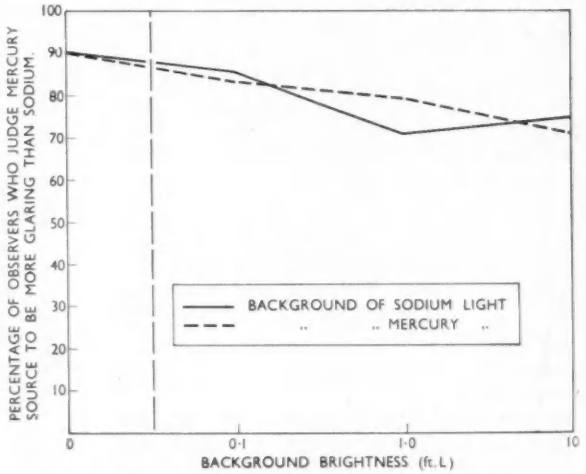


Fig. 3.—' Glare factor ' for mercury/sodium comparison with various background brightnesses. Equal intensities from the two sources.

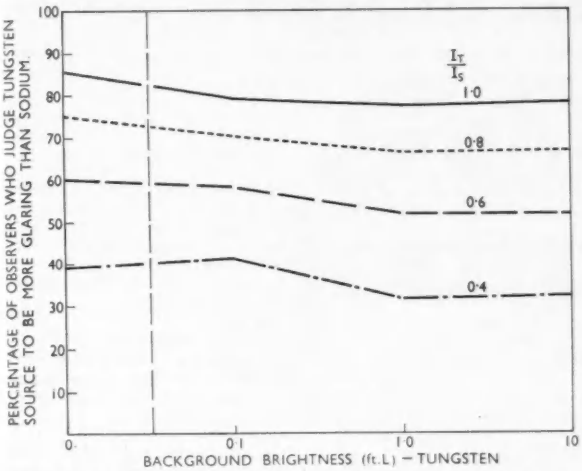


Fig. 4.—'Glare factor' for tungsten/sodium comparison with various background brightnesses (tungsten light), and various ratios of $\frac{\text{Intensity from tungsten source}}{\text{Intensity from sodium source}}$

that neutral glass filters were also required. These were carefully calibrated to ensure that their transmissions were the same for mercury and sodium radiation. In fact, the transmission to mercury radiation was a few per cent higher than to sodium, but this was compensated for by adjusting the current through the sodium lamp.

With this arrangement it was possible to present to the observers the two sources at luminances ranging from about 55 cd/in^2 down to 0·002 cd/in^2, and to ask which source appeared more glaring when the measured luminances were the same. The result was that at the highest luminance, 85 per cent of the observers found the mercury source more glaring and as the luminance decreased the percentage fell. The observers were about equally divided when the luminance of the two sources was 1·5 cd/in^2, and at lower luminances slightly less than 40 per cent of observers found the mercury source more glaring, i.e. rather more than 60 per cent found sodium more glaring. It would be expected, of course, that opinion would be equally divided at all luminance levels provided photopic vision was employed, and the discrepancy in these experiments is probably within experimental error at the lower luminance levels. The results, however, do support the suggestion that as luminance is increased, the visual response to mercury radiation increases more rapidly than to sodium radiation. The measurements need repeating several times to make the results more reliable.

A subsidiary experiment has also been made to determine whether the long wave ultra-violet radiation emitted by the mercury source could account for the results obtained in the main tests. A clear ultra-violet absorbing filter was interposed between the observer and the sources: but this did not affect the general judgment of relative glare.

Other experiments are planned, for example on source size; but at present, it can only be reported that the reasons for the phenomenon are not understood. When they are better understood it may be possible to say how far the results are applicable to street lighting. Suppose, for example, the sensitivity of the eye to light from a mercury source increases with increasing luminance more rapidly than it does for light from a sodium lamp: then if two roads are lighted with mercury and sodium lamps respectively so that the road surfaces appear equally bright, the mercury sources will appear brighter than the sodium sources.

At present it can only be stated that in the conditions of the experiment the majority of observers found the mercury source more glaring than the sodium. How much more the discomfort glare is for a given observer is not known: and in this connection it may be significant that not all observers found mercury more glaring than sodium. The method of test used was essentially to make a photometer of the two bright areas by placing them side by side; this is very sensitive to small differences. Other experiments have used less direct methods which did not disclose any significant difference. It may be that the differences recognised by observers in this experiment would be less apparent if the sources were seen successively: also these differences may be small compared with the variations in glare which occur in practice in street lighting installations.

It is hoped to investigate the street lighting problem by several further experiments and in particular by comparing two installations with different sources but otherwise similar in such respects as road surface, mounting height, spacing and light distribution.

TECHNICAL LITERATURE

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS, BY MEMBERS OF THE G.E.C. AND ITS ASSOCIATED COMPANIES

HANDLING IRON AND STEEL WITH ELECTRIC MAGNETS

By D. Amies (Witton Kramer Electric Tool and Hoist Works).

Mechanical Handling, February, 1952

The first lifting magnets were introduced at the turn of the century and have been brought into use progressively in replacing primitive means of manhandling pig iron, ingots and so forth. Designs are now available for such extreme service as handling hot billets at 650 deg. C. and for underwater salvage. In all cases the individual duty must be carefully considered when choosing the correct type of magnet. The three types of magnet available are : circular, rectangular and bipolar.

The type of control gear for lifting magnets varies with the nature of the load. An important modern application is the use of a magnetic tube conveyor for transferring steel tubes from hot galvanising baths to cooling tanks, thus ensuring an even flow of material.

The article concludes with a survey of the many possible applications of this branch of mechanical handling, perhaps the most interesting being its use in handling semi-liquid iron sludge in the manufacture of dyestuffs.

HIGH-FREQUENCY BRIDGE WITH VARIABLE RATIO ARMS (499)

By J. E. Houldin and G. T. Thompson (G.E.C. Research Laboratories).

The bridge described is intended for measurements on aerials, cables and similar impedances in the frequency range 10-100 Mc/s. The circuit uses variable ratio arms, in the form of a circular arc of transmission line with a movable feed point.

The range of parallel resistance of the unknown impedance is from one quarter to four times the value of the standard resistor, which may have any value between 50 and 250 ohms. The reactance range of the bridge varies ; it is equivalent to $\pm$ 45 pF when the ratio arms are equal.

MODERN KINEMA LIGHTING

By G. Robinson (Illuminating Engineering Department).

British Kinematography, Vol. 21, No. 4, October, 1952.

The author discusses recent developments and current trends in kinema interior and exterior lighting, particularly in connection with the application of fluorescent tubes. The relative economics of various lamps are given and the British regulations regarding safety lighting, together with experimental work on desirable auditorium illumination levels are described.

Dimming, proscenium and screen surround lighting are considered and examples of some recent installations are illustrated.

BLENDED LIGHT

By S. Anderson (Illuminating Engineering Department).

Trans. I.E.S. (London), Vol. XVIII, No. 1, 1953.

The paper deals with the application of blended light from filament and discharge lamps in industry. Methods of blending, suitable reflectors and the light distribution obtained are compared. Overall efficiencies and power factors are given and some subsidiary considerations are mentioned.

Illustrations of typical lighting equipment and installations are given.

FLUORESCENT DISCHARGE—TUBE CIRCUITS AND OPERATING PROBLEMS

By J. Cates (G.E.C. Research Laboratories).

Proc. I.E.E., Vol. 100, Pt. 2, August, 1953.

The author reviews a wide variety of operating circuits and types of control gear. The merits and disadvantages of certain circuits are discussed and the influence of wave form distortion on the tube and on the supply network is indicated.

AN AUDIO-FREQUENCY MIXING SYSTEM FOR SPACED DIVERSITY RECEIVERS (525)*

By E. G. Hamer and D. W. Elson (G. E. C. Research Laboratories).

Jour. Brit. I.R.E., Vol. XII, No. 2, pp. 123-128, February, 1953,

After a general review of the principles of diversity reception, the special case of a V.H.F. diversity scheme using spaced receivers suitable for a mobile radio system is discussed. The various methods which could be used are outlined, and the method actually used described in more detail. A design of a mixing unit is given, based on the subjective listening performance necessary for a multi-station V.H.F. area coverage scheme.

CHANGES IN SECONDARY AND THERMIONIC EMISSION FROM BARIUM OXIDE DURING ELECTRON BOMBARDMENT (529)*

By J. Woods and D. A. Wright (G.E.C. Research Laboratories).

Brit. Jour. of Applied Physics, Vol. 4, pp. 56-62, February, 1953.

During electron bombardment, the secondary emission from films of barium oxide changes with time in a manner which depends on the film thickness. The changes are due to a reduction process forming an excess of metal within the oxide ; subsequent oxidation restores the initial behaviour. The thermionic emission from the films also varies with thickness, and increases as the tendency of the secondary emission to decay increases. Electron bombardment at room temperature lowers the thermionic emission of a thin film by increasing the oxygen concentration at the outer surface, but at temperatures above 500 deg. C. this oxygen accumulation does not occur, and the reduction process is a very effective one for activating the thermionic emission.

THE INFLUENCE OF BENDS AND ELLIPTICITY ON THE ATTENUATION AND PROPAGATION CHARACTERISTICS OF THE H_{01} CIRCULAR WAVEGUIDE MODE (518)*

By G. D. Sims (G.E.C. Research Laboratories).

Institution of Electrical Engineers Monograph No. 58.

The generation and propagation of the H_{01} circular waveguide mode is discussed, in the light of such theory as is at present available and of certain new experimental results. The Jouguet theory of propagation in curved circular guides has been verified at a wavelength of 3·2 cm. The attenuation of the H_{01} mode has been measured at 3·2 cm. by a multiple reflection technique in a long closed copper guide $4\frac{1}{2}$ in. in diameter. The result obtained—3·4 db/km is about three times the theoretical figure, the excess being explainable in terms of losses due to surface roughness and ellipticity of the guide.

*** A limited number of reprints is available of those papers marked with an asterisk. Copies may be obtained on application to the Editor, G.E.C. Journal, Magnet House, Kingsway, W.C.2.**